Development of the Bicycle Compatibility Index: A Level of Service Concept, Final Report

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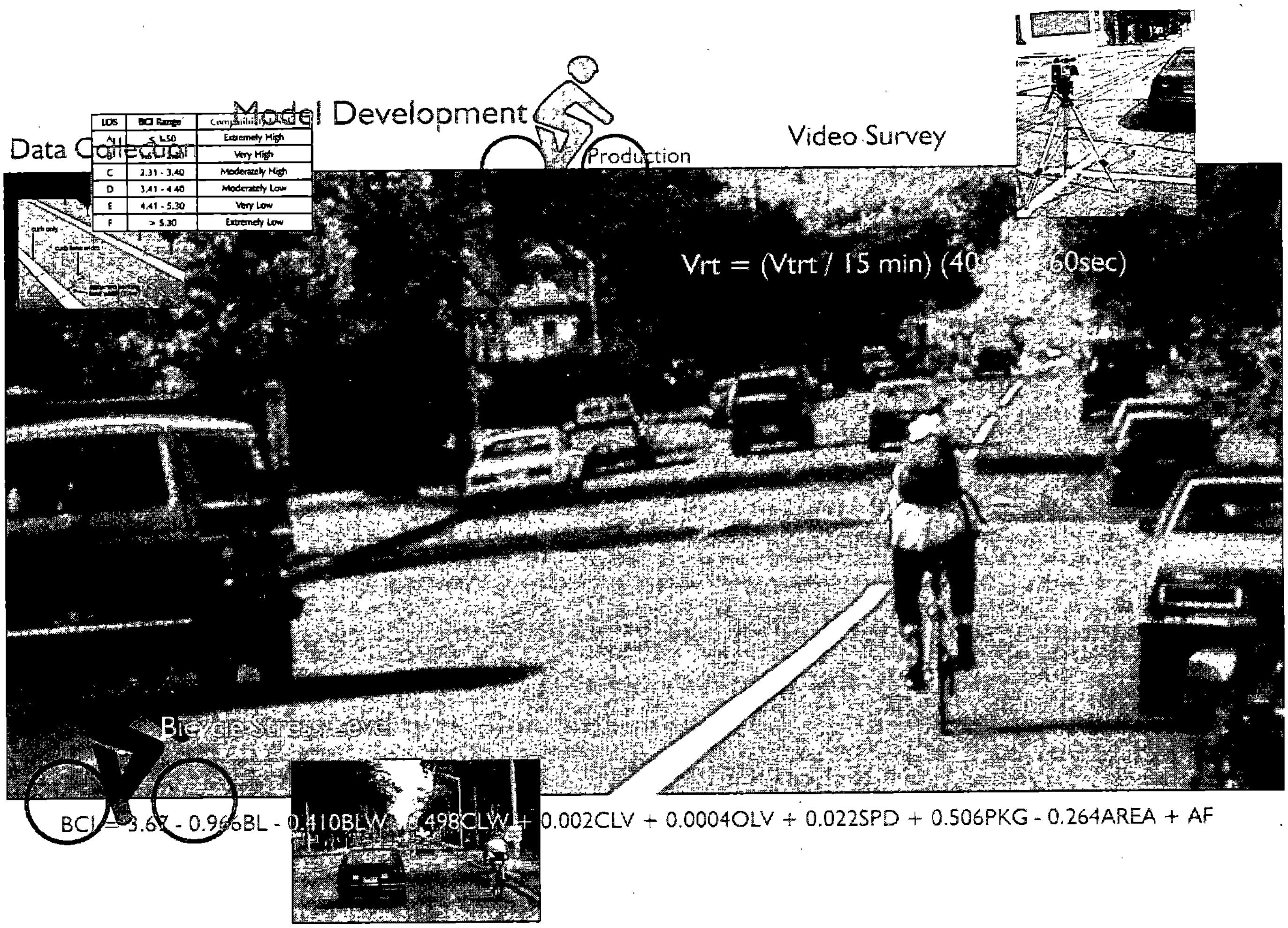

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Federal Highway Administration

Research and Development
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FOREWORD

The vision of the 1998 Federal Highway Administration National Strategic Plan is to create the best transportation system in the world, a transportation system that is safe, efficient, and intermodal, allowing all Americans to have access within and beyond their communities. This transportation system will have significantly reduced crashes, delays, and congestion; roads that protect ecosystems and air quality; and will accommodate pedestrians and bicyclists.

One method of accommodating bicycle travel is to develop or improve roadways for shared use by both motor vehicles and bicycles. Currently, there is no widely accepted methodology used by transportation professionals that allows them to determine how compatible a roadway is for allowing smooth operation of both bicycles and motor vehicles. This report documents the research effort undertaken to develop the Bicycle Compatibility Index (BCI), a tool that evaluates the capability of urban and suburban roadway sections to accommodate both motorists and bicyclists. The BCI methodology will allow practitioners to evaluate existing facilities and determine possible improvements and to determine operational and geometric requirements for new facilities.

This report should be of interest to State and local bicycle coordinators, transportation engineers, planners, and researchers involved in the design of bicycle facilities within the highway system.

A. George Ostensen, Director
Office of Safety and Traffic Operations,
Research and Development

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16. Abstract

Presently, there is no methodology ***widely accepted*** by engineers, planners, or bicycle coordinators that will allow them to determine how compatible a roadway is for allowing efficient operation of both bicycles and motor vehicles. Determining how existing traffic operations and geometric conditions impact a bicyclist's decision to use or not use a specific roadway is the first step in determining the bicycle compatibility of the roadway. This research effort was undertaken to develop a methodology for deriving a bicycle compatibility index (BCI) that could be used by practitioners to evaluate the capability of specific roadways to accommodate both motorists and bicyclists. The BCI methodology was developed for urban and suburban roadway segments (i.e., midblock locations that are exclusive of major intersections) and incorporated those variables which bicyclists typically use to assess the "bicycle friendliness" of a roadway (e.g., curb lane width, traffic volume, and vehicle speeds). The developed tool will allow practitioners to evaluate existing facilities in order to determine what improvements may be required as well as to determine the geometric and operational requirements for new facilities.

Also discussed in this report is the application of the developed methodology used for rating midblock segments to intersections and an assessment of the validity of such an approach for rating the bicycle compatibility of intersections.

In addition to this final report, there is a companion report titled *The Bicycle Compatibility Index: A Level of Service Concept, Implementation Manual* (FHWA-RD-98-095) that contains applied examples of the BCI methodology.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3

NOTE: Volumes greater than 1000 l shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

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Chapter 1 Introduction

Background

The goals of the United States Department of Transportation (USDOT) as stated in the ***National Bicycling and Walking Study*** are: 1) to double the number of trips made by bicycling and walking, and 2) to simultaneously reduce by 10 percent the number of pedestrians and bicyclists killed or injured in traffic crashes.[1] Meeting the first of these goals will require a substantial increase in the number of trips made by bicyclists using on-road or shared facilities. This increased exposure could, in turn, jeopardize the second goal of improved safety unless careful consideration is given to the needs of both bicyclists and motor vehicle operators in the enhancement of existing roadways or development of new roadways. To develop or improve roadways for shared use by these two modes of transportation, one must begin by evaluating existing roadways and determining what is considered "user-friendly" from the perspective of the bicyclist.

Presently, there is no methodology ***widely accepted*** by engineers, planners, or bicycle coordinators that will allow them to determine how compatible a roadway is for allowing efficient operation of both bicycles and motor vehicles (*see figure 1*). Determining how existing traffic operations and geometric conditions impact a bicyclist's decision to use or not use a specific roadway is the first step in determining the bicycle compatibility of the roadway.

In recent years, several studies have been undertaken to develop some systematic means of measuring the operational condition of roadways for bicycling (*see appendix A for a detailed discussion*). These efforts have included the development of models based on the geometrics of roadway segments and intersections, pavement conditions, traffic volumes, speed limits,

Figure 1. Practitioners need a tool that will allow them to determine the compatibility of their roadways for bicycling.

and other variables. Each of these models produces an index that can be compared with a subjectively developed rating scale to assess the specific roadway segment or intersection.[2,3,4] Another effort developed a series of recommended lane, shoulder, and bicycle lane widths that are subjectively assigned on the basis of traffic volumes, motor vehicle operating speeds, type of bicyclist, and other variables.[5]

The one missing element in each of these studies is the lack of recognition of the bicyclists' perspectives After all, these are the individuals who will ultimately decide if a roadway meets their personal comfort level for riding in the presence of motor vehicle traffic.

Table 1. Example of stress levels developed by the Geelong Bikeplan Team.[6]

AADT	Traffic Speed (km/h)	Adequate Lane Width[1]	Stress Level[2]
< 4000	72	Yes	1
	72	No	1
	56	Yes	1
	56	No	1
4000 - 10,000	72	Yes	2
	72	No	3
	56	Yes	1
	56	No	2
10,001 - 15,000	72	Yes	3
	72	No	4
	56	Yes	2
	56	No	3
> 15,000	72	Yes	4
	72	No	5
	56	Yes	3
	56	No	4

[1]Adequate lane widths: Two-lane, < 72 km/h = 4.3 m
Two-lane, ≥ 72 km/h = 4.9 m
Multilane, < 72 km/h = 3.7 m
Multilane, ≥ 72 km/h = 4.3 m

[2]Stress levels: 1=low, 2=low-moderate, 3=moderate, 4=high, 5=very high

Bicycle stress level

In 1978, the Geelong Bikeplan Team in Australia understood the importance of the bicyclist's perspective and incorporated it into a concept known as the ***bicycle stress level*** to better define the bicycling suitability of roadways from the viewpoint of the bicyclist.[6] This concept was developed, in part, on the assumption that bicyclists not only want to minimize the physical effort required when choosing a roadway on which to ride, but that they also want to minimize the mental effort, or ***stress***, that results from conflict with motor vehicles, interaction with heavy vehicles, and having to concentrate for long periods of time while riding on high-volume and high-speed roadways.

The team members drew upon their personal bicycling experience with specific roadways to quantitatively define the concept. The variables considered to have the most impact on the stress level of a bicyclist were curb lane width, motor vehicle speed, and traffic volume. For various combinations of these three variables, team members assigned values from one to five to reflect the amount of stress they experienced when riding under those conditions. A value of **one** indicated a very low level of stress while a **five** indicated a very high level. Shown in table 1 are examples of the stress levels developed. While these values are subjective (based on the experience of team members), it was the first attempt to use the perspective of the bicyclist to assess the compatibility of roadways for bicycling.

In 1994, Sorton and Walsh used the ***bicycle stress level*** concept in an effort to relate bicyclists' perspectives on various types of roadways to specific geometric and traffic operating conditions.[7] Their project represented the first attempt to gather perspectives from persons other than research team members; thus, the results were not based solely on the subjective interpretations of researchers.

In a small-scale research effort employing segments of videotape from different street environments, three groups of bicyclists (experienced, casual, and youth) were asked to rate several urban and suburban roadway segments with varying degrees of traffic volume, motor vehicle speeds, and curb lane, shoulder, or bicycle lane widths. The ratings were to reflect the level of stress they would experience (i.e., how uncomfortable they would be) riding on a specific segment with respect to each of the variables noted above. The scale used for rating the segments and the authors' interpretation of the scale is shown in table 2. At the extremes, a stress level of one indicates that all types of bicyclists (older than age 10) could safely be accommodated on the facility, while at stress level five, virtually no bicyclists would ride on the roadway.

For each of the three variables rated, the authors developed quantitative values that they believed to be associated with each stress level. This step involved examining the engineering literature for empirical data related to the operations of bicycles or motor vehicles, determining the end points for each variable that would be considered low and high stress situations for the bicyclist, and then interpolating between these points to assign quantitative values to the other stress levels. The values developed and assigned to each of the stress levels are shown in table 3.

The ratings produced by the various groups of bicyclists in the survey were then compared with the empirically derived values. Ultimately, the results showed a very high correlation between the values derived and the ratings of the bicyclists, indicating that bicyclists can recognize differences in the levels of traffic volume, motor vehicle speed, and lane width, and that these

Table 2. Suggested interpretation of bicycle stress levels.[7]

Stress Level	Interpretation
1-Very Low	Street is reasonably safe for all types of bicyclists (except children under 10).
2-Low	Street can accommodate experienced and casual bicyclists, and/or may need altering[1] or have compensating conditions[2] to fit youth bicyclists.
3-Moderate	Street can accommodate experienced bicyclists, and/or contains compensating conditions to accommodate casual bicyclists. Not recommended for youth bicyclists.
4-High	Street may need altering and/or have compensating conditions to accommodate experienced bicyclists. Not recommended for casual or youth bicyclists.
5-Very High	Street may not be suitable for bicycle use.

[1] "Altering" means that street may be widened to include wide curb lane, paved shoulder addition, etc.
[2] "Compensating condition" can include street with wide curb lanes, paved shoulders, bicycle lanes, low volume, etc.

Table 3. Quantitative geometric and operational values developed and assigned to each stress level.[7]

Variable	Stress Level	Quantitative Value
Curb Lane Volume (vehicles/h)	1	≤ 50
	2	150
	3	250
	4	350
	5	≥ 450
Curb Lane Width (m)	1	≥ 4.6
	2	4.3
	3	4.0
	4	3.7
	5	≤ 3.3
Motor Vehicle Speed (km/h)	1	≤ 40
	2	50
	3	60
	4	65
	5	≥ 75

differences are consistently reflected in their comfort or stress level. The results also indicate that the stress levels of bicyclists are correlated to the real-world conditions present on the roadways (e.g., changes in lane widths).

Bicycle level of service

The ***Highway Capacity Manual*** defines levels of service (LOS) as "...qualitative measures that characterize operational conditions within a traffic stream and their perception by motorists and passengers."[8] The terms used in describing each LOS (designated as A through F, with LOS A being the most desirable) include speed and travel time, freedom to maneuver, comfort/convenience, and traffic interruptions.

The concept of LOS was introduced to qualify the operational characteristics associated with various levels of vehicles or persons passing a given point during a specified time period. For this reason, LOS in reality is a qualifier of conditions related to vehicle or person through-put rather than a qualifier of conditions related to individual comfort level. This fact is revealed by examining the measures of effectiveness (MOE's) used to define the ranges of LOS for various types of facilities. For freeways, the MOE is density (passenger cars/mi/h); for signalized intersections, the MOE is average stopped delay (s/vehicle); and for arterials, the MOE is average travel speed (mi/h). Each of these MOE's is directly related to vehicle through-put.

For bicycles, LOS criteria are not defined in the ***Highway Capacity Manual***. The discussion on bicycles is primarily limited to the impact of bicycles on motor vehicle LOS. If the implied definition of LOS (i.e., as related to vehicle through-put) is used, there are very few on-street facilities in the United States where LOS criteria would be needed simply because of the low bicycle volumes. However, the descriptive terms for LOS used in the written definition are applicable to bicycle transportation. For a bicyclist, the qualitative terms comfort and convenience and freedom to maneuver are critical factors with respect to determining their quality of service on a given facility.

Referring back to the definition for LOS, the user's perception of the operational conditions is an important element in terms of assigning a LOS designation to a facility. The ***bicycle stress level*** concept incorporates the perceptions of bicyclists to assess the bicycle compatibility of roadways on a five-point scale. In many ways, each point on the scale can be thought of as representing a different LOS for bicyclists. For example, a roadway with a very low stress level would be considered by bicyclists to offer a high degree of comfort, which would be represented by the LOS A designation.

In the current study, the bicycle compatibility index (BCI) reflects the comfort levels of bicyclists on the basis of observed geometric and operational conditions on a variety of roadways. The correlation of these comfort levels with the conditions of the roadway in the development of the BCI model allows the user to determine bicycle LOS for roadway segments by incorporating these geometric and operational characteristics into the model. A complete discussion of the BCI model and subsequent LOS designations is provided in chapter 4.

Objectives and scope

The primary objective of the current study was to develop a methodology for deriving a bicycle compatibility index (BCI) that could be used by bicycle coordinators, transportation planners, traffic engineers, and others to evaluate the capability of specific roadways to accommodate both motorists and bicyclists. The BCI methodology was developed for urban and suburban roadway segments (i.e., midblock locations that are exclusive of intersections) and incorporated those variables that bicyclists typically use to assess the "bicycle friendliness" of a roadway (e.g., curb lane width, traffic volume, and vehicle speeds).

A secondary objective of this study was to apply the developed methodology used for rating midblock segments to intersections and assess whether such an approach was valid for rating the bicycle compatibility of intersections. As with the roadway segment methodology, those variables used by bicyclists to assess the "bicycle friendliness" of intersections were identified, and a limited amount of data were collected and analyzed to assess the effectiveness of the methodology.

This research effort expanded upon the work of Sorton and Walsh and the Geelong Bikeplan Team to produce a practical instrument that can be used by practitioners to predict bicyclists' perceptions of a specific roadway environment and ultimately determine the level of bicycle compatibility that exists on roadways within their jurisdictions. The developed tool will allow practitioners to evaluate existing facilities in order to determine what improvements may be required as well as to determine the geometric and operational requirements for new facilities to achieve the desired level of bicycle service.

Organization of the report

The results of this research effort are provided in two separate reports. This final report contains the comprehensive results of the study. The second report is the implementation manual and provides practitioners a guide on how to apply the BCI methodology in response to planning and engineering issues.

In this final report, chapter 2 contains the development and validation of the research methodology, including the results of the pilot study. Chapter 3 discusses the data collection efforts while chapter 4 provides details on the data analysis. In chapter 5, the application of the developed methodology to intersections is discussed. Finally, a summary of the results, conclusions, and an applied example are provided in chapter 6. There are also four appendices, one of which includes a detailed literature review of those few studies that have attempted to model bicycle safety or bicycle operating conditions on the basis of roadway geometrics, traffic conditions, and other variables.

Chapter 2

Development & validation of the methodology

The methodology used in obtaining the perspectives of bicyclists in this study consisted of having participants view numerous roadway segments captured on videotape and rate these segments with respect to how comfortable they would be riding there under the geometric and operational conditions shown. The advantages of using this video-based methodology include:

1) There are no risks to bicyclists. In other words, bicyclists do not have to ride in or be exposed to conditions which they would consider uncomfortable or unsafe. This fact allows for the inclusion of conditions, such as large trucks or buses on very narrow lanes, which could not be safely evaluated using on-the-road bicyclists.

2) Specific variables can be presented to bicyclists in a controlled environment. For example, all subjects can be exposed to the same exact number of vehicles, i.e., traffic volume, or to the same special conditions such as right-turning traffic or heavy vehicles. This form of variable control is virtually impossible by having bicyclists actually ride on the roadway. Bicyclists riding the same segment during two different time periods may be exposed to different levels of traffic volume, traffic composition, or other factors, and thus their ratings of the same segment of roadway would be based on different operating conditions.

3) The number of operational and geometric conditions to which a subject is exposed can be much greater than can be experienced in the field. For example, the participants in the pilot study described below rated the 13 sites in less than 15 min from the video, but it took almost 3 h to drive to and rate all 13 locations in the field. If all geometric and operational conditions desired for the study are in several cities (as was the case in this effort), it is simply impractical to present all conditions to the same group of bicyclists.

4) The same set of geometric and operational conditions can be examined and rated by bicyclists in several municipalities. This advantage allows for the direct comparison of ratings between bicyclists in different regions of the country or communities that may vary in terms of bicycling facilities or bicycle "friendliness."

This application of videotape technology to obtain ratings from bicyclists was used by Sorton and Walsh in several bicycle research efforts and was shown to produce consistent rating results from one study to the next.[7] However, there had never been any formal validation of the video methodology. Prior to proceeding with this methodology in the full-scale data collection effort of this research study, a pilot study was undertaken with the primary objective of validating the video technique, i.e., determining how well the participants' comfort ratings of various geometric, traffic volume, and speed conditions recorded when watching a videotape compared with the participants' comfort ratings when seeing the locations in the field. There were also several secondary objectives, including evaluating camera positions, determining the amount of videotape to shoot at a given site, determining the length of video clips necessary for an individual to make definitive ratings, and exploring different rating scales.

Site selection

With limited resources and an objective of comparing participants' ratings from watching a videotape with their ratings from seeing the locations in the field, only those conditions believed to be the most difficult to discern on the videotape were included in the pilot effort. Preliminary observations by project staff showed that differences in motor vehicle speeds and volumes were relatively easy to recognize on the videotape. Similarly, it was easy to determine the differences between cross-sections with and without a paved shoulder or bicycle lane. The most difficult of the cross-section elements to determine from the videotape was lane width when there was no paved shoulder or bicycle lane. Thus, the pilot study included only roadway segments with standard or wide curb lanes and no paved shoulders or bicycle lanes, i.e., the most difficult situations for viewers to differentiate (*see figure 2*).

The pilot survey was conducted in Madison, Wisconsin. After examining several potential sites and collecting speed data to determine the 85th percentile speeds, 13 locations were selected for inclusion in the pilot survey. The distribution of sites by lane width and 85th percentile speed is shown in table 4. The geometric and operational characteristics associated with each location are shown in table 35 in appendix B. Curb lane widths ranged from 3.1 m to 5.5 m; 85th percentile speeds ranged from 48 to 72 km/h; and traffic volumes ranged from 3,550 to 26,650 vehicles/day. The sites selected also represented an extensive range of combinations of these variables, from low-speed, low-volume, narrow-lane locations to high-speed, high-volume, wide-lane locations. Examples of two of the selected sites are shown in figures 3 and 4.

Video production

Producing the videotape for the pilot survey consisted of filming each location and editing the videotapes to find the appropriate selections to be representative of each site. Since the participants in the survey would be visiting the sites in the field in addition to viewing them on the videotape, a schedule was developed so that each site was filmed at approximately the

Figure 2. The pilot study focused on roadways with various curb lane widths, exclusive of bicycle lanes and paved shoulders, since this was the variable believed to be the most difficult for viewers to discern from the video.

Table 4. Distribution of sites selected for the pilot study by lane width and 85th percentile speed.

85th %tile Speed	Lane Width (m)		
	≤ 3.4	3.7 - 4.0	≥ 4.3
< 56 km/h	3	1	3
≥ 56 km/h	2	2	2

same time the participants would be on location making the field survey ratings.

Filming was conducted for 15 min at each location. The camera position (*see figure 5*), which had been thoroughly evaluated prior to the pilot survey, was on the curb as close to the lane as possible with the lens aimed parallel to the roadway such that the view seen was evenly distributed with the roadway on the left side of the screen and the roadside (sidewalks, houses, etc.) on the right side. The height of the lens was between 1.4 and 1.5 m above the road surface to approximate the eye height of a bicyclist. Finally, the camera was positioned as far upstream of any signalized intersections or driveways as possible to ensure that the ratings were based on the geometric and operational characteristics present along the typical roadway section and not on the presence or characteristics of major downstream intersections or driveways that were signalized.

Once the videotaping was completed, curb lane volumes and total volumes were counted and recorded for each 10-s period throughout the entire 15 min of videotape for each location. Two 40-s intervals representing different volume conditions were then selected for each site. The two volume conditions for each site included one that was the most "representative" of conditions during the 15 min of taping and one that included exactly 4 vehicles passing in the curb lane during 40 s, equivalent to 360 vehicles/h/ lane.

This selection process resulted in a "representative volume" 40-s segment and a "uniform volume" 40-s segment for each of the 13 sites. These 26 segments were included on the survey video twice, which would allow for the examination of how consistent the participants were in rating the same roadway conditions. In addition to these 52 clips (26 x 2), there were two clips at the beginning that were provided as practice clips and would not be used in the evaluation. With the exception of the two practice clips, the various clips were randomly ordered for placement on the survey videotape, ensuring that the same location never appeared in two sequential clips. Each 40-s clip of interest was then copied onto the survey tape with 5 s of blank tape placed between consecutive clips. The number of each consecutive clip was then placed in the 5-s blank intervals; these numbers were added as an aid to any participant who lost their place during the survey. An audible beep also was added to each of the clips; the beep was placed on the tape such that it could be heard when there were 10 s left of the 40-s clip and provided an indication to the participants that they needed to complete their ratings within the next 10 s.

Video survey

The schedules for the participants were arranged such that half of the 24 participants would complete the video survey first and then the field survey. The other half would complete the field survey first and then the video survey. This approach allowed for an examination of any differences that may have resulted due to the order of completing the survey.

The video survey was conducted each of four evenings over a 2-h period, with the number of participants ranging from three to eight per evening. The participants began

Figure 3. High-volume multilane pilot study site with an 85th percentile speed of 55 km/h and a curb lane width of 3.4 m.

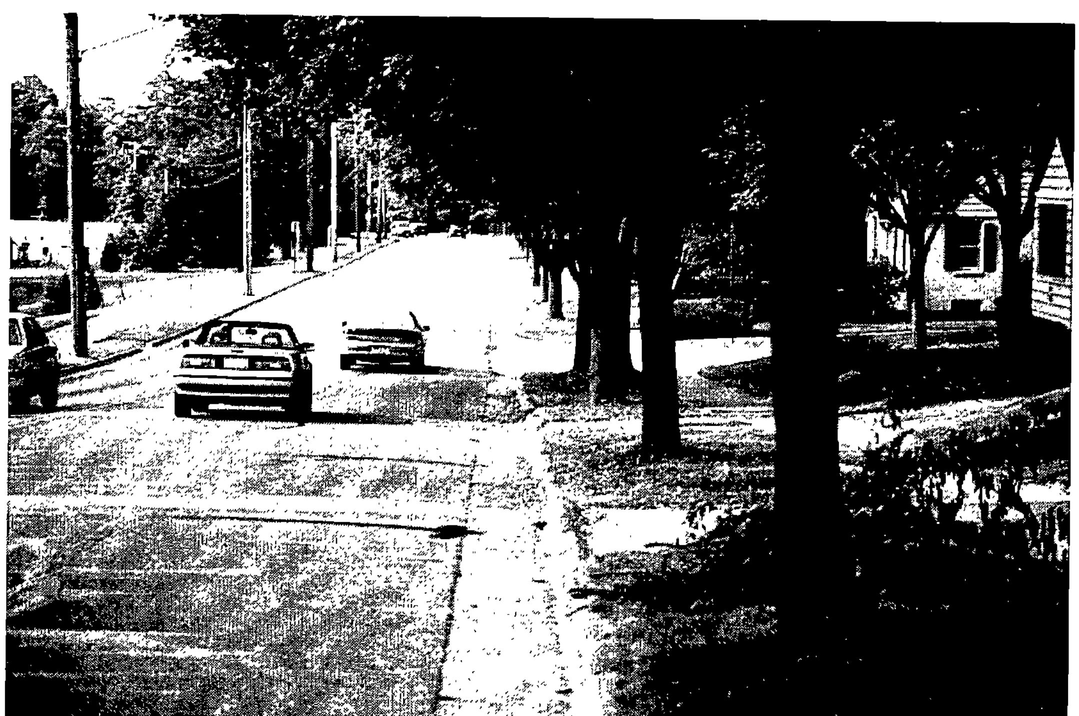


Figure 4. Low-volume two-lane pilot study site with an 85th percentile speed of 48 km/h and a curb lane width of 5.5 m.

Figure 5. The camera was positioned on the curb as close to the lane as possible at a height of 1.4 to 1.5 m with the lens aimed parallel to the roadway.

by filling out a questionnaire (*see appendix C*) that was intended to provide an indication of experience level with regard to riding on urban and suburban streets. In the prior work by Sorton and Walsh, it had been shown that less experienced bicyclists tended to have higher ratings, i.e., be less comfortable, than more experienced bicyclists.[7] Thus, it was also possible that these differences in perception by experience level may be a factor in any differences between the video survey ratings and the field ratings.

Once the questionnaire was completed, the survey forms and rating scales (*see appendix C*) were distributed, and the participants were then given some background information regarding the study and told the objectives of the research effort. Instructions for completing the video survey were then read to the group (*see appendix C*) and questions were answered to clarify or further define the process. Once everyone was comfortable with the process, the videotape was started. The size of the projected image was approximately 1.2 m by 1.8 m, and the sound of the projector was adjusted to emulate the sound of traffic one would hear when riding a bicycle on the roadway.

Field survey

The field survey was conducted over a 4-h period each of four mornings, with the number of participants ranging from four to eight per morning. The participants were given clipboards containing the survey forms and rating scales (*see appendix C*) when they arrived at the meeting site. The participants were then given some background information regarding the study and told the objectives of the research effort. Instructions for completing the field survey were then read to the group (*see appendix C*) and questions were answered to clarify or further define the process. Once everyone was comfortable with the process, the participants were taken to each of the 13 locations, in the order that was established prior to the videotaping, to make the ratings. At each site, the van was parked and everyone, as a group, walked to the point where they were to observe the traffic and roadway conditions. This observation point was the same location where the camera had been positioned to ensure that conditions were being observed in the field and on the video from the same vantage point. The participants were told which direction of traffic to observe (the direction closest to them) and instructed to make their ratings based on what they observed during the next 2 min. During this 2-min period, a traffic count was done in order to have a record of the volumes and types of vehicles being observed by the participants on various days. A typical group making the ratings from the roadside vantage point at one of the locations is shown in figure 6.

Figure 6. Participants in the field survey of the pilot study stood adjacent to the direction of travel of interest and indicated how comfortable they would be riding a bicycle under the conditions observed.

Data analysis

As previously noted, the primary objective of this pilot study was to validate the video methodology, i.e., determine how well the participants' comfort ratings recorded when watching the video ***matched*** the participants' ratings when viewing the location in the field. Since each of the 24 participants (subjects) viewed the 13 sites both from the videotape and in the field, the most stable and reliable analyses are based on the 312 (24 × 13) combined pairs (video vs. field) of observations. Thus, the analysis primarily focused on the combined sample of comfort ratings, including the overall rating as well as those related to curb lane width, traffic volume, and traffic speed. For brevity, only a summary of the results is provided below; a complete discussion of the statistical analysis is provided in appendix B.

The results of the analyses indicated that the participants' video ratings matched reasonably well to the field ratings for all four variables examined (overall, speed, curb lane width, and volume). The number of exact matches for the 312 site-by-participant pairs ranged from 30.8 percent to 43.6 percent, depending on the variable. However, the percentage of pairs that differed by no more than one rating level increased dramatically and ranged from 81.1 to 87.2 percent. These numbers and the corresponding statistics produced as part of the analysis indicate that the great majority of the video and field ratings were in substantial agreement.

It should also be noted that for all variables examined, there were very few values in the extremes of the contingency tables. For example, there were no sites where any participant rated any variable as a one from the video and a six in the field or vice versa. Similarly, there were almost no cases where variables rated as a two under one scenario were rated as a five under the other scenario. This lack of extremes, or conversely the concentration of values along the main diagonal, is another indicator of the reliability of the video methodology to accurately reflect the field comfort ratings of bicyclists.

Conclusions

Overall, the results from the data analysis showed the video methodology to be a valid technique for obtaining realistic perspectives of bicyclists pertaining to comfort levels under varying roadway conditions. The pilot study was also used as a proving ground for the survey procedures and provided insight into other issues that were incorporated into the full-scale data collection effort. Some of the more important issues and the resulting consequences for the study included:

- The video survey procedures employed were very efficient and resulted in no problems. Similarly, the procedures employed in the videotaping, editing, and production of the survey tape resulted in a quality product. Thus, the same procedures were carried forward to the larger study.
- At the conclusion of the video survey, participants were asked to discuss the variables other than volume, speed, and curb lane width that influenced their comfort ratings. The variables that were commonly cited included presence of large trucks or buses, heavy right-turning traffic, and number of driveways in the scene. Thus, these variables were examined in greater detail in the full-scale effort.
- During the initial stages of this study, considerable thought and discussion went into the development of the rating scale to reflect the bicyclists' level of comfort. The project team ultimately decided that the study participants should be evaluating their level of comfort as it related to their perceived level of risk. Thus, a six-level scale was used in the pilot study, where a rating of one implied that the condition of interest (e.g., lane width, speed of traffic, or traffic volume) represented virtually no risk and a rating of six implied that the condition represented unacceptably high risk. Discussions with the participants in the pilot study after the survey was completed indicated that the majority of the subjects thought that "perceived risk" accurately reflected their comfort level. However, a few of the more experienced bicyclists preferred a scale with less of a safety connotation. The one term that the more experienced riders seemed to like was "tolerance." A rating of one in this case would indicate that the condition of interest would be tolerated for an unlimited amount of time while a six would indicate that the condition of interest would not be tolerated for any length of time.

The preferred alternative, however, was to simply use "comfort level" as the rating term with some qualifying statements to indicate that comfort does not refer to the smoothness of the ride. Thus, for the full-scale data collection effort, a six-point scale incorporating "comfort level" was developed and used (*see chapter 3*). The most important factor in the development and use of any rating scale was that it was understood and interpreted the same way by all participants. The simplicity of the term "comfort level" was believed to have the best chance of achieving this level of understanding and uniform interpretation.

Chapter
3
Data collection

Site selection

The sites that were filmed and included in the study were selected in several cities within five distinct regions of the country, as shown in figure 7. These cities represent a range of geographic conditions present in the United States and included:

- Eugene and Corvallis, Oregon.
- Cupertino, Palo Alto, Santa Clara, and San Jose, California.
- Gainesville, Florida.
- Madison, Wisconsin.
- Raleigh and Durham, North Carolina.

Many of these cities have a variety of on-street bicycle facilities that range in widths, traffic volumes, and motor vehicle speeds. This variety in facility types made it feasible to maximize the range of conditions included in the video survey.

Prior to selecting the sites, a matrix was developed that stratified several of the geometric and operational characteristics (*see table 5*). The intent of the matrix was to ensure that the sites selected did indeed represent the variety of conditions a bicyclist may encounter in an urban/suburban environment. As a starting point, ***bicycle lane/paved shoulder*** facilities were separated from ***standard/wide curb lane*** facilities. Bicycle lane facilities and paved shoulder facilities were grouped into a single category for two reasons. First, the two facility types are indistinguishable from each other on video unless the pavement markings or signs designating the bicycle lane are visible in the video frame. Being able to always incorporate a bicycle lane marking or sign into the video frame was not possible since these signs and markings are sometimes spaced at very large intervals or are at locations where the filming could not be done (e.g, directly in front of a

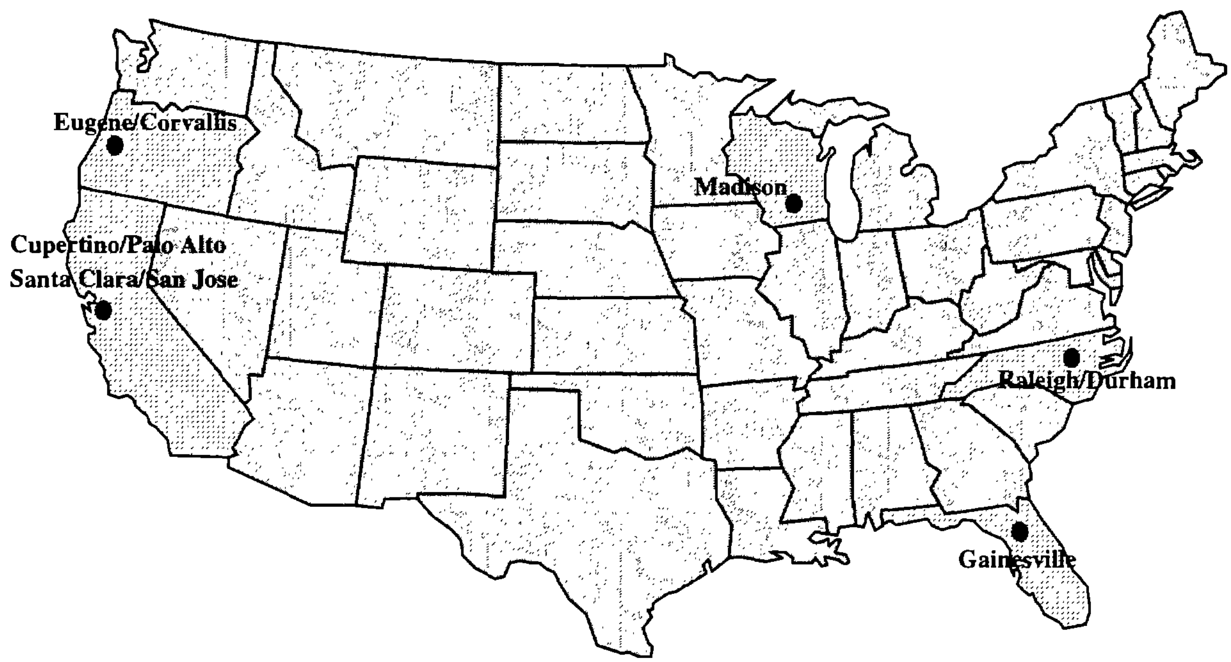


Figure 7. Sites included in the video survey were filmed in six cities/regional areas located throughout the United States.

shopping center driveway or in the middle of a horizontal curve). Second, prior research has shown that midblock interactions between motorists and bicyclists on bicycle lanes and paved shoulders are essentially identical; in other words, the two parties operate their vehicles in the same manner in the presence of each other regardless of facility type.[9] Other variables that were used as site selection criteria included vehicle speed, number of lanes, and lane or shoulder width. As indicated in the table, two levels for each of these variables were used to further stratify the sites.

Altogether, 67 sites were selected for inclusion in the video survey. The number of sites in each of the matrix cells is shown in table 5. The geometric and operational characteristics also ranged considerably across the 67 sites and included: 1) curb lane widths from 3.0 to 5.6 m; 2) motor vehicle 85th percentile speeds from 40 to 89 km/h; traffic volumes from 2,000 to 60,000 vehicles/day, and 4) bicycle lane/paved shoulder widths from 0.9 to 2.4 m. Other characteristics that varied included number of intersecting driveways, type of roadside development (e.g., residential, commercial, etc.), type of street (e.g., arterial, collector, etc.), number of through travel lanes, and the presence or absence of gutter pans, sidewalks, and medians. Within several of these cells, sites with on-street parking were also selected to examine the effect of such designs on bicyclists' comfort levels. Shown in figure 8 are four of the study sites illustrating the range of roadway conditions.

Field data collection

The data collection effort in this study was conducted in three phases. The first phase included videotaping the selected street segments and collecting supplemental geometric or operations data. The second phase included reducing the collected video data into a format that could be used in the video survey and preparing the survey videotape. The final phase included the video survey and reducing the survey responses into a format for the analysis.

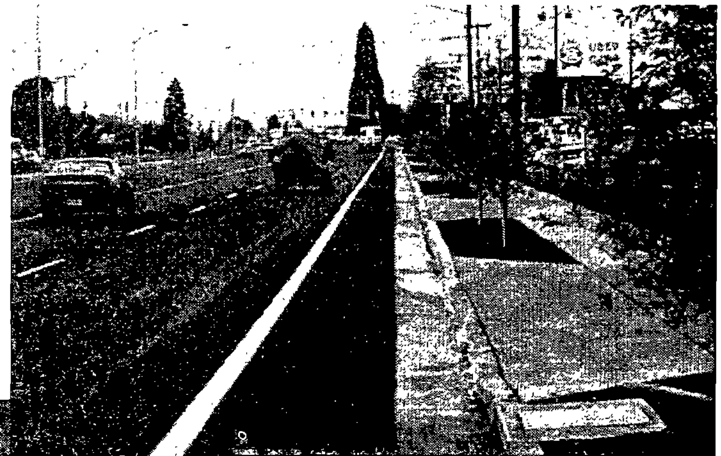
The procedures followed for filming each location were developed in the pilot study, as described in chapter 2, and are briefly reiterated here. At each of the selected roadway segments, 15 min of video were recorded. All sites were filmed during off-peak hours (between 9 AM and 4 PM) to make the data collection as efficient as possible and, at the same time, to provide the widest range of volume conditions. It

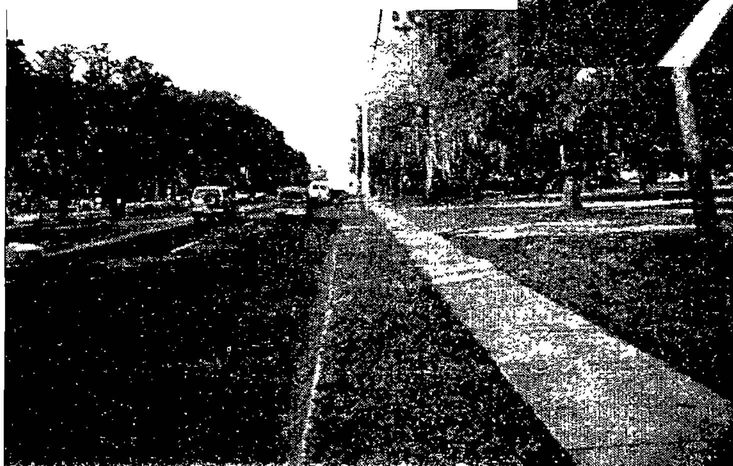
Table 5. Number of sites selected for the video survey stratified by type of facility, speed, lane width, and number of lanes.

Facility Type	Bicycle Lane/Paved Shoulder (m)				Standard/Wide Curb Lane (m)			
85th %tile Speed	≤ 56 km/h		> 56 km/h		≤ 56 km/h		> 56 km/h	
Lane Width (m)*	≤ 1.2	> 1.2	≤ 1.2	> 1.2	< 4.3	≥ 4.3	< 4.3	≥ 4.3
Two-Lane	5	6	4	5	4	3	3	3
Multilane	1	2	7	9	4	3	4	4

* Lane width for the "bicycle lane/paved shoulder" sites refers to the width of the bicycle lane or paved shoulder; for the "standard/wide curb lane" sites, it refers to the width of the curb lane.

Multilane arterial with a two-way left-turn lane.
85^{th} percentile speed=77 km/h
curb lane width = 3.7 m
paved shoulder width = 0.9 m
AADT = 26,500 vehicles/day





Undivided multilane arterial adjacent to the University of Florida.
85^{th} percentile speed = 48 km/h
curb lane width = 4.6 m
AADT = 38,500 vehicles/day
no gutter pan

Two-lane collector in residential area.
85^{th} percentile speed = 48 km/h
curb lane width = 4.1 m
bicycle lane width = 1.2 m
AADT = 8,000 vehicles/day

Two-lane collector near Oregon State University with on-street parking.
85^{th} percentile speed = 48 km/h
curb lane width = 3.8 m
bicycle lane width = 1.2 m
parking lane width = 2.4 m
AADT = 16,000 vehicles/day

Figure 8. The sites selected for the video survey included a broad range and an extensive combination of geometric and operational characteristics, as illustrated by these four locations.

was determined during the pilot study that within 15 min of videotape from a given location, there were a number of 40-s intervals that could have been selected to reflect various volume conditions, from almost no traffic to rather congested conditions. The video camera was positioned at the same height at each location, namely between 1.4 and 1.5 m above the road surface to be representative of the eye height of a bicyclist. At locations without parking, the camera was positioned on the curb as close to the lane as possible and aimed parallel to the roadway (*previously shown in figure 5 in chapter 2*). At locations with on-street parking, the camera was positioned at the left edge of the parking lane as close to the travel lane as possible (*see figure 9*). Again it was aimed so that it was parallel to the roadway. In addition to the videotaping at each location, supplemental geometric or traffic operations data were also collected, including additional speed data, confirmation of lane widths, and specific pavement marking information.

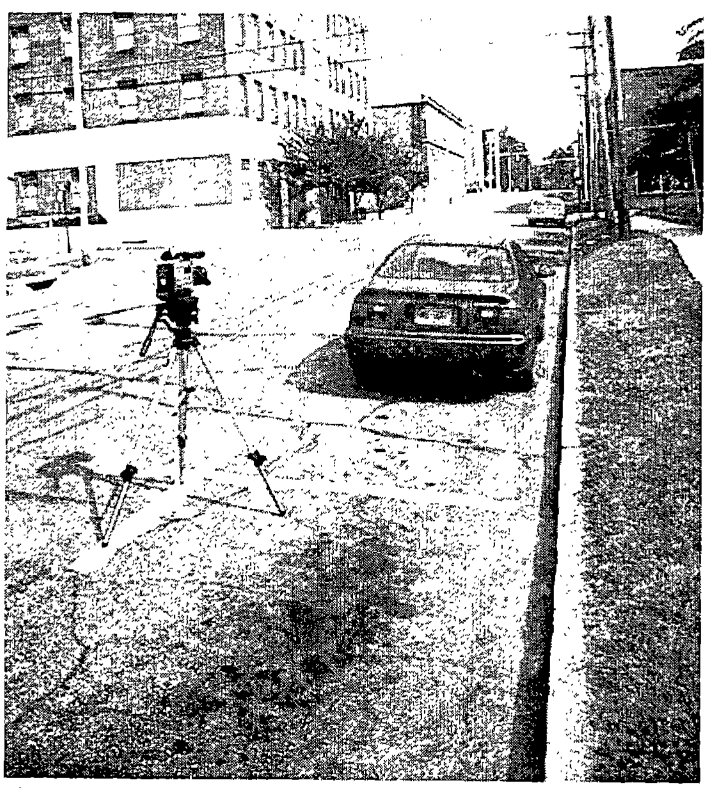


Figure 9. At locations with on-street parking, the camera was positioned at the left edge of the parking lane as close to the travel lane as possible at a height of 1.4 to 1.5 m with the lens aimed parallel to the roadway.

Video production

After the videotaping was completed for each set of roadway segments in each city, the video editing began, which consisted of viewing each 15-min video and selecting specific 40-s intervals that best conveyed the variables of interest. (A 40-s interval was determined to provide an adequate amount of time for an individual to rate the roadway and traffic conditions of interest in the pilot study.) The first step in this process was to record the curb lane volumes and total volumes for each 10-s period throughout the entire 15 min of videotape for each location. Any 10-s intervals containing heavy trucks, buses, or bicycles were also noted (*see appendix C for an example of a completed form*). The truck and bus intervals were identified so that specific heavy vehicle clips could be included in the survey that would allow for a comparison of the same sites with and without heavy vehicles in the scene. The intervals with heavy right-turning volumes and vehicles pulling into or out of on-street parking spaces were noted for similar reasons.

Intervals with bicyclists in the scene were also noted and discarded for two reasons. First, it would not have been feasible to obtain video of all locations with traffic stream bicyclists. Second, and more importantly, the ratings of a given roadway segment by a subject should be based on the subject's own interpretation of conditions and should not be influenced by the fact that an unknown bicyclist with an unknown skill level is riding on the roadway.

Once the volume counts were completed, representative 40-s intervals were selected for each site that contained passenger vehicles and light trucks only.

Determining how many vehicles should be included in the representative interval was done using the following equation:

$$V_r = (V_t/15\ \text{min})(40\ \text{s}/60\ \text{s})$$

where:

V_r = representative curb lane volume for the 40-s interval, and

V_t = total curb lane volume observed during the 15 min of videotape.

The selection of any supplemental intervals, e.g., ones with heavy vehicles, was done after all representative intervals were selected. The type and number of supplemental intervals selected included:

- Large trucks and buses - Seven clips were selected that included a variety of large trucks and/or buses. An example of one of the sites included in the survey where trucks and buses were prevalent is shown in figure 10.
- Right-turning vehicles - Two clips were selected that included a high volume of traffic turning right into driveways or minor intersections along the block.
- Parking vehicles - Two clips were selected that included vehicles pulling into or out of on-street parallel parking spaces.
- Practice clips - Two clips were selected to help the subjects get acclimated to the process and to indicate the range of conditions that could be anticipated. One of the clips was a high-volume, high-speed scenario with a moderate lane width while the other was a low-speed, low-volume condition with a bicycle lane.

Once representative 40-s intervals and the supplemental 40-s intervals were selected for all sites, the process of copying these intervals to the video survey tape began. With the exception of the practice clips, the 40-s clips were placed onto the survey tape in random order while ensuring that no representative clip and special condition clip from the same site appeared sequentially. Each 40-s clip was copied onto the survey tape with 5 s of blank tape placed between consecutive clips. The number of the upcoming clip was then placed in the 5-s blank intervals as an aid to any participant

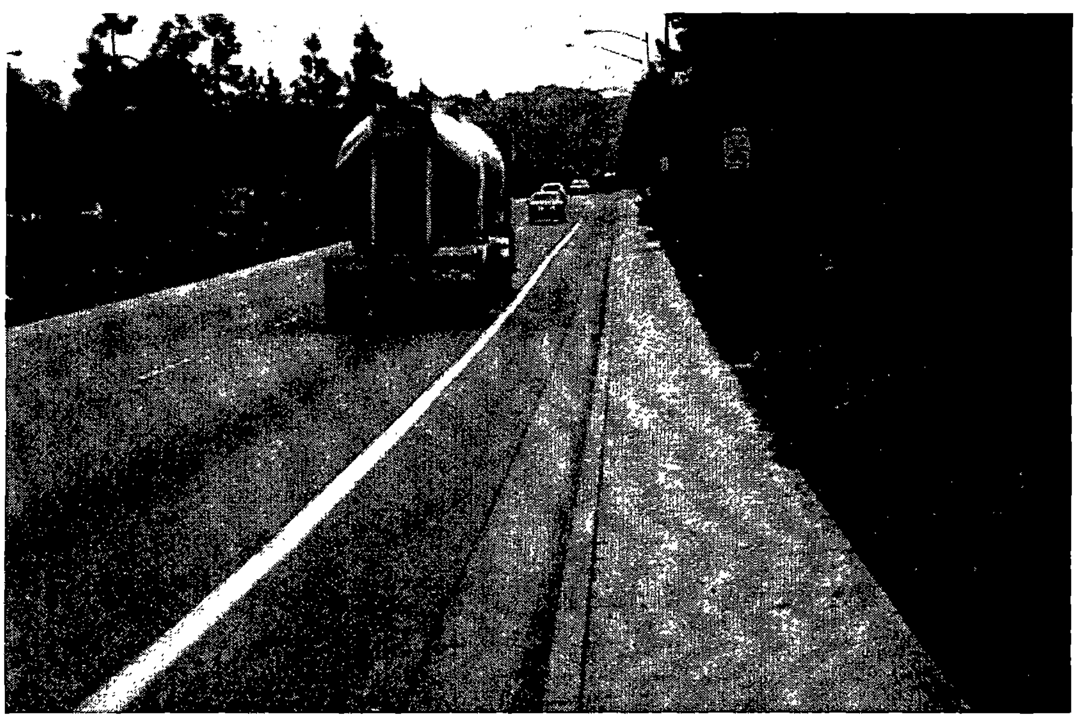


Figure 10. Supplemental video clips were included on the video survey tape to examine the effects of large trucks and buses on bicyclists' comfort levels.

who may have lost track of the appropriate clip number during the survey. An audible beep was also added to each video clip and placed on the tape so it could be heard when there were 10 s left on each 40-s clip; this beep reminded the subjects that they needed to complete their ratings of the segment shown.

Video survey

The final phase of the data collection effort was the conduct of the video survey. As shown in figure 11, the survey was conducted in three cities that range in population and are geographically distributed, namely Chapel Hill, North Carolina; Olympia, Washington; and Austin, Texas. One important criterion for a city to be included in the survey was the availability of both experienced and casual bicyclists to participate in the survey. All of the cities selected have a number of commuting bicyclists as well as casual and recreational bicyclists. The survey participants were recruited in each city through newspaper advertisements, radio announcements, posted flyers, and announcements at bicycle club meetings. Each participant in the study received a $20 payment upon completion of the survey. The total number of participants from all three cities was 202.

The survey began with each participant completing a questionnaire (*see appendix C*). The results from the questionnaire were used to assess the bicycling experience level of each subject. It was hypothesized that the less experienced riders would be less comfortable than their experienced counterparts under the same geometric and operating conditions. Once the questionnaire was completed, the survey forms and rating scales (*see appendix C*) were distributed. The rating scale used was a six-point scale in which a **one** indicated that the individual would be "extremely comfortable" riding under the conditions shown and would not hesitate to ride there while a **six** indicated that the individual would be "extremely uncomfortable" riding under the conditions shown and thus would never ride there.

The participants were then given some background information regarding the

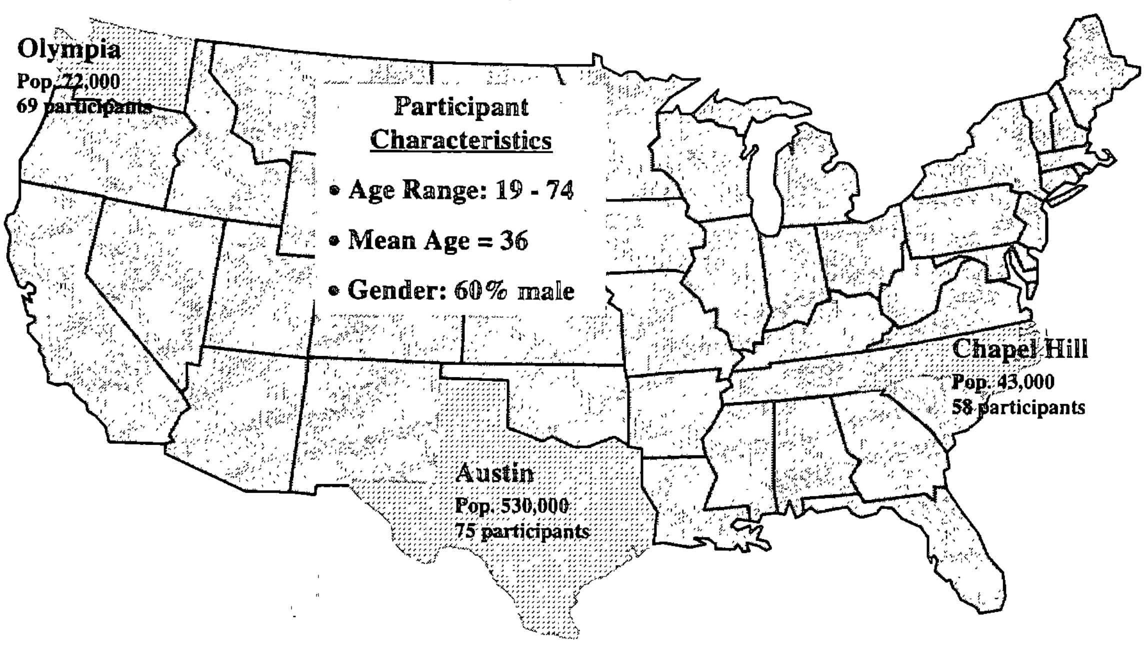


Figure 11. The video survey was conducted in three cities and included 202 participants with the characteristics shown.

study, including the objectives of the research effort. Next, instructions for completing the video survey (*see appendix C*) were distributed and read to the group, and questions were answered to further define or clarify the process. Once everyone was comfortable with the instructions, the videotape containing the midblock locations was started. The size of the projected image was approximately 1.2 m by 1.8 m, and the sound of the projector was adjusted to emulate the sound of traffic one would hear if riding a bicycle in the street. A short break was taken at the midpoint of the survey, approximately 30 min into the videotape.

For each video clip, the participants provided four comfort level ratings using the six-point scale. They provided a rating with respect to how comfortable they would feel as a bicyclist considering the number of vehicles on that roadway (**traffic volume**). They provided a rating based on how comfortable they would feel considering the **speed** of the traffic. They provided a rating based on how comfortable they would feel considering the space available to ride a bicycle in the road (**width**). Finally, they provided a rating for the roadway as a whole that represented their **overall** comfort level based on the three measures just noted plus any other measures that they considered important in determining their overall comfort level as a bicyclist. Per the instructions, volume, speed, and width could be rated in any order, and the overall rating was done last.

Chapter

4

Data analysis

The two primary questions addressed by the analysis of the data collected under this project were focused on the development of the bicycle compatibility index (BCI) model:

Can the comfort level ratings of bicyclists be used to develop a BCI model that can be used by bicycle coordinators, transportation planners, traffic engineers, and others to evaluate the capability of specific roadway segments to accommodate both motorists and bicyclists in their jurisdiction?

If so, what roadway and traffic operations variables are needed as input for this index?

In addition to these primary questions, several secondary questions were also addressed as part of the analysis, including:

1) Are there differences in the comfort level ratings of experienced riders vs. casual riders with respect to any of the roadway or traffic operations variables?

2) Do bicyclists in different geographic regions have the same perceptions of bicycle compatibility; i.e., are there differences in the comfort level ratings of bicyclists in the three survey cities?

3) What are the interrelationships between the variables being rated by the respondents; i.e., what interactions are important in making the ratings?

Effect of bicyclist experience

In the prior research effort conducted by Sorton and Walsh, the experience level of the bicyclist significantly affected the comfort level of the bicyclist.[7] For example, when asked to rate their comfort level with respect to curb lane width (on a five-point scale), the experienced riders produced a mean value of 3.00 while the casual riders produced a higher mean rating of 3.34, indicating less comfort with the widths provided. Similar results were found with respect to the motor vehicle speed and traffic volume variables.

From these past results, it was reasonable to hypothesize that differences in experience levels would also be reflected in the comfort level ratings of participants in this study. Specifically, those bicyclists with the most experience would be most comfortable with the geometric and operating conditions shown and thus would have lower ratings when compared with the less experienced bicyclists.

The first step in evaluating the experience levels of bicyclists on the comfort level ratings was to produce clusters of bicyclists with similar experience. The responses to the questionnaire completed by the participants served as the mechanism to produce such groups. The final question on the questionnaire asked participants to classify themselves into one of two specified categories according to their experience riding on urban and suburban streets. A total of 60 percent stated that they were "comfortable riding under most traffic conditions, including major streets with busy traffic and higher speeds."

A logistic regression analysis of this response on other questionnaire responses indicated that the self-classification of 'comfortable riding under most conditions' was positively associated with male gender, percent of cycling on major streets, and miles per week that they typically ride. With the exception of these factors, the self-classification of experience did not appear to be related to other experience response variables and thus was not used as the sole criterion in developing groups by experience level.

Instead, cluster analyses were performed to determine clusters or homogeneous groups of bicyclists. Two-cluster and three-cluster models were fitted using the centroid method of 'distance' between clusters. The analyses produced clusters according to a multivariate score based on all variables. While the definition of each cluster could not be simply defined, the results did provide insight into which variables are most important in terms of assessing experience level. Those variables included trip purpose, number of trips/wk, distance ridden/wk, and types of facilities used. Ultimately, these exploratory cluster analysis results were used as the basis for defining three homogeneous groups (*see table 6*) of bicyclists as follows:

1) Experienced Commuter Bicyclists

Bicyclists in this group make the largest percentage of their trips (60 percent) for the purpose of commuting to/from school or work. This group also rides more days/wk than the other groups, longer distances, and makes more trips/wk. They also tend to ride on major streets more often than the other groups.

2) Experienced Recreational Bicyclists

Bicyclists in this group make 80 percent of their trips for the purpose of recreation or exercise. They tend to ride fewer days/wk than experienced commuter bicyclists but more days/wk than casual recreational bicyclists. This same trend is also true for number of trips/wk and distances ridden/wk. Finally, bicyclists in this group are less likely than experienced commuter bicyclists to ride on major streets but more likely to ride on bicycle paths.

3) Casual Recreational Bicyclists

Bicyclists in this group are similar to experienced recreational bicyclists in that they make the largest percentage of their trips (70 percent) for recreational/exercise purposes. However, this group rides the fewest days/wk, makes the fewest number of trips/wk, and rides the fewest number of mi/wk. This group also rides the least amount of their trips on major streets and the most on bicycle paths when compared with the other groups.

As previously described in chapter 3, each participant provided four ratings on a scale of one (extremely comfortable) to six (extremely uncomfortable) for four variables: **width** (or space available to ride), **speed** of traffic, **volume** of traffic, and **overall**. Shown in figure 12 are the mean comfort level ratings for each of these variables and each group of bicyclists. For all four variables rated, the experienced recreational bicyclists and the experienced commuter bicyclists had identical or very similar mean values. On the other hand, the casual recreational bicyclists had slightly higher mean ratings when compared with the other groups, confirming what had previously been found by Sorton and Walsh.[7] The differences ranged from a low of 0.3 to a high of 0.5. While these higher mean ratings by the one group of bicyclists were significantly different from the other groups for all four variables rated, it is questionable as to whether these differences can be considered practical. These differences also raise the question of how to develop and apply the BCI model in the real world where bicyclists of all levels may be riding on a given roadway. This issue is addressed in more detail later in this chapter.

Regional evaluation

One concern with the development of any model that is based on the perceptions of individuals is that these perceptions may differ depending on the geographic region. If this is true, then separate models must be developed for the various regions where such differences occur. Thus prior to any model development in this study, the ratings from the three survey cities (Olympia, WA; Austin, TX; and Chapel Hill, NC) were compared. The distribution of bicyclists by

Table 6. Characteristics of bicyclist groups used in the analysis.

Characteristic	Group 1 Experienced Commuter	Group 2 Experienced Recreational	Group 3 Casual Recreational
Number of bicyclists	79	78	34
Percent male	67	59	41
Mean age	34	36	36
Trip purpose (percent): Recreation/exercise	16	80	70
Commuting to/from school or work	60	10	18
Shopping	14	4	3
Visiting/Other	10	6	8
Percent riding on: Major streets	45	35	20
Residential streets	35	33	44
Bicycle/multiuse paths	13	21	27
Sidewalks/other	7	11	9
Percent trips/wk: < 5 trips/wk	9	42	79
5-10 trips /wk	42	41	18
>10 trips /wk	49	17	3
Average number of days/wk bicycle used	4.9	3.5	2.2
Percent who ride: < 5 mi/wk	0	0	100
5-20 mi/wk	35	50	0
21-40 mi/wk	35	26	0
> 40 mi/wk	29	24	0
Percent who classify themselves as "experienced" bicyclists	73	59	32

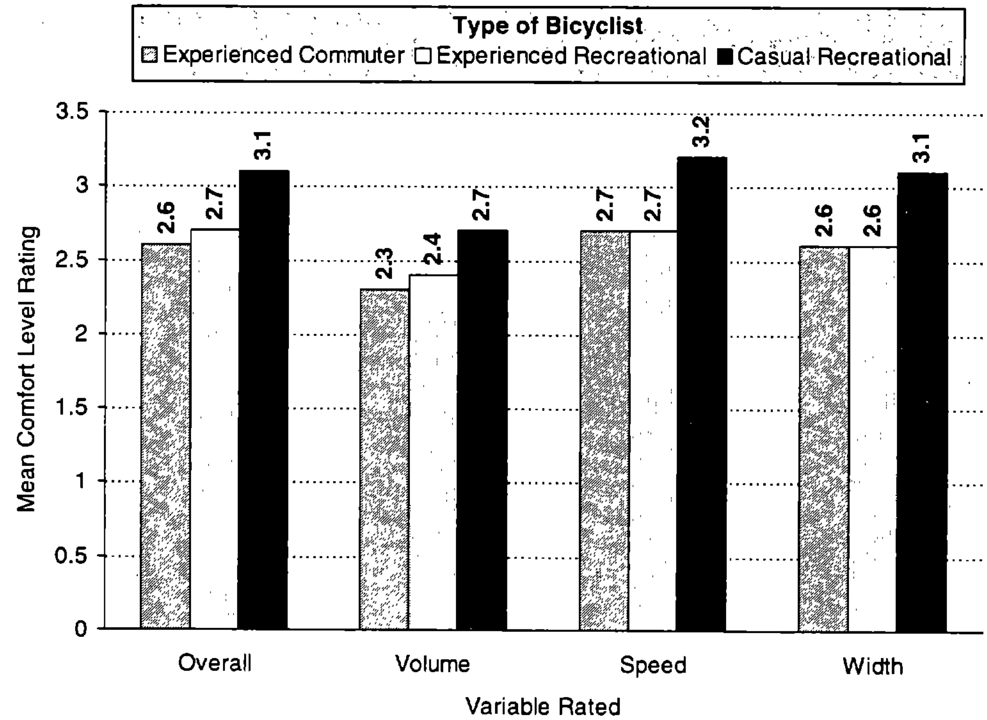


Figure 12. Mean comfort level ratings by type of bicyclist for the four variables rated in the video survey.

type (experienced commuter vs. experienced recreational vs. casual recreational) was similar in the three regions. As shown in figure 13, there were virtually no differences between locations in the comfort level ratings of any of the variables. A statistical evaluation of the data confirmed the apparent lack of differences, indicating that the groups participating in the three States generally perceived comfort level, and thus bicycle compatibility, in the same way across the six-point rating scale.

Model development

Determining the key roadway and traffic variables that may influence a bicyclist's decision to ride or not ride on a given roadway and incorporating those variables into a model was the primary objective of the data analysis. The analysis approach was to use regression modeling to determine all main effects, search for significant square and interaction terms, and ultimately eliminate all variables that were not significant at the level of $p \leq 0.01$. Thus, the variable selection strategy considered each candidate independent variable equally. Those that appeared in the final model were the ones that were significantly and independently related to the ratings (or outcome variable) after all other variables were taken into account.

The geometric and operational variables collected in the field or from the video clips and included in the regression modeling are shown in table 7. Using these variables as independent variables and the mean rating for each roadway segment (across subjects) as the response variable, regression models were developed to predict the overall comfort level of bicyclists. Models were developed for all bicyclists as well as for the three separate groups of bicyclists previously defined. Shown in table 8 are the four models developed. Three of the four models include the same eight significant variables; only the model for the experienced commuter bicyclist is different in that respect. For that particular model, the variables of bicycle lane width (**BLW**) and type of roadside development (**AREA**) were not significant, but the simple presence of a bicycle lane or paved shoulder accounts for a much greater decrease in the index value, somewhat offsetting the effects of these variables in the other models.

As noted previously in this chapter, the mean comfort level ratings for casual recreational bicyclists were significantly greater than for the other groups of bicyclists. For that reason, models were produced separately for each of the groups, as shown in table 8. In general, the model for casual riders begins with a slightly higher intercept value (3.83 vs. 3.62 and 3.65 for the experienced groups) and the coefficients for each significant variable result in a greater impact on the BCI for this group. For example, with all other variables held constant, each km/h increase in the 85th percentile speed increases the index by 0.026 for casual riders and 0.021 for experienced riders. While this increase appears to be very small, the cumulative effect over all variables in the model will generally increase the BCI more for **casual** bicyclists than for **all** bicyclists. The magnitude of this increase depends on the geometric and operational characteristics of the roadway. As examples, consider the two sites in this study that produced the lowest and highest BCI values for **all** bicyclists at 1.19 and 5.60, respectively. Using the model for the **casual recreational** bicyclist, these same sites produce values of 1.33 and 5.98, respectively. Thus, the BCI model for **casual** bicyclists can be expected to produce BCI values that are typically between 0.14 (= 1.33 - 1.19) and 0.38 (= 5.98 - 5.60) greater than the values produced by the model for **all** bicyclists.

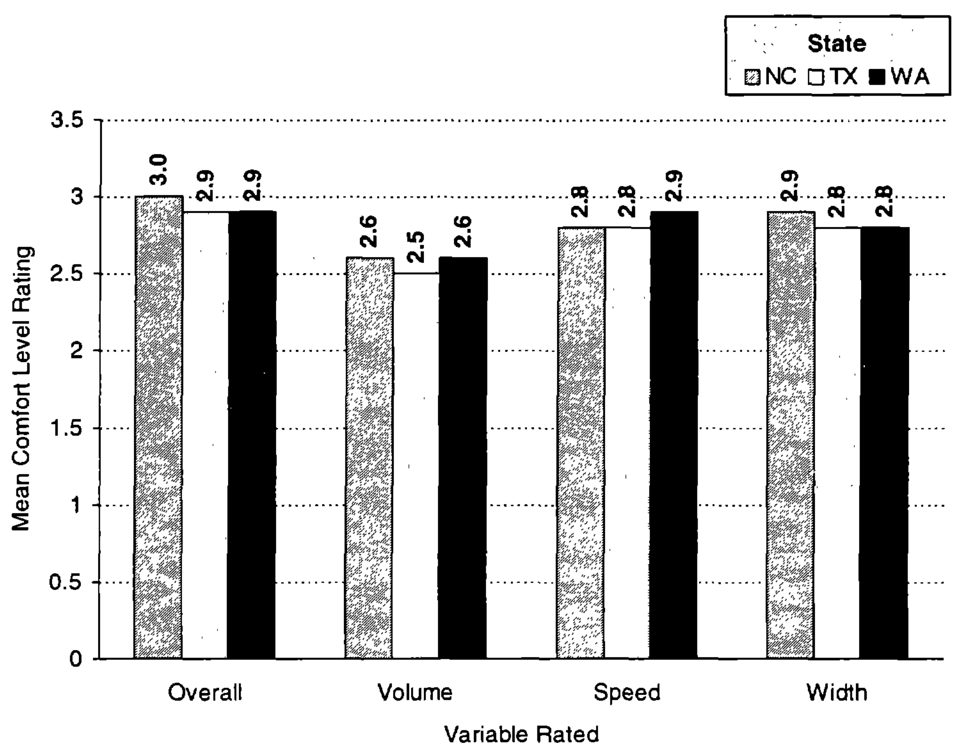


Figure 13. Mean comfort level ratings by State for the four variables rated in the video survey.

Table 7. Variables included in the regression modeling analysis.

Variable Name	Description	Variable Codes/Units
NL	Number of lanes	Both directions (2 through 8)
DT	Number of travel directions	One-way street = 1 Two-way street = 2
CLW	Curb lane width	Meters, to the nearest tenth
BL	Presence of a bicycle lane or paved shoulder	No = 0 Yes = 1
BLW	Bicycle lane (paved shoulder) width	Meters, to the nearest tenth
CLV	Curb lane volume	Hourly volume
OLV	Other lane(s) volume - same direction	Hourly volume
SPD	85th percentile speed	Km/h
SL	Speed limit	Km/h
PKG	Presence of a parking lane with at least 30 percent of the spaces occupied	No = 0 Yes = 1
GP	Presence of a gutter pan	No = 0 Yes = 1
GPW	Gutter pan width	Meters, to the nearest tenth
MED	Presence of a median	No = 0 Yes = 1
TWLTL	Presence of a two-way-left-turn lane	No = 0 Yes = 1
DWD	Driveway density	0 driveways/100 m = 1 1 - 3 driveways/100 m = 2 > 3 driveways/100 m = 3
SW	Presence of sidewalks	No = 0 Yes = 1
SWS	Sidewalk separated from roadway	No = 0 Yes = 1
AREA	Type of roadside development	Residential = 1 Other type = 2

Table 8. Bicycle Compatibility Index (BCI) models for all bicyclists and for the three groups of bicyclists by experience level.

Bicycle Compatibility Index Model		R^2-value
BCI (All Bicyclists) =	3.67 - 0.966**BL** - 0.410**BLW** - 0.498**CLW** + 0.002**CLV** + 0.0004**OLV** + 0.022**SPD** + 0.506**PKG** - 0.264**AREA**	0.89
BCI (Experienced Commuter) =	3.65 - 1.560**BL** - 0.521**CLW** + 0.0015**CLV** + 0.0004**OLV** + 0.021**SPD** + 0.433**PKG**	0.85
BCI (Experienced Recreational) =	3.62 - 0.846**BL** - 0.448**BLW** - 0.510**CLW** + 0.002**CLV** + 0.0005**OLV** + 0.021**SPD** + 0.525**PKG** - 0.278**AREA**	0.87
BCI (Casual Recreational) =	3.83 - 0.936**BL** - 0.539**BLW** - 0.510**CLW** + 0.002**CLV** + 0.0005**OLV** + 0.026**SPD** + 0.583**PKG** - 0.290**AREA**	0.91

More important than the differences between the models developed for the various experience levels is the application of the appropriate model in the real world. The most probable scenario is that bicyclists of all experience levels will be riding on a particular segment of roadway, and thus the bicycle compatibility of that roadway should be determined on the basis of the average skills of all bicyclists. Thus, it is recommended that the model developed for **all** bicyclists be used for most applications; use of the model for the casual recreational bicyclist should only be done when the practitioner knows that the majority of the riders along a specific route are indeed casual bicyclists.

Further examination of the model for **all** bicyclists reveals that the variable having the greatest effect on the BCI is the presence or absence of a bicycle lane (or paved shoulder). If a bicycle lane or paved shoulder (**BL**) is present and all other variables in the model are held constant, the index is reduced by 0.966, indicating a higher level of comfort. Similarly, as the width of the roadway increases and all other variables are held constant, so does the comfort level of the bicyclist. For each meter of bicycle lane or paved shoulder present (**BLW**), the index is reduced by 0.410; for each meter of curb lane width (**CLW**), the index is reduced by 0.498.

The range of conditions included in the development of the model should be representative of most urban and suburban roadway conditions. However, since the sites included in the development contained a limited range of widths, volumes, and speeds, the model should not be extrapolated beyond the values shown in table 9. For example, the model is only appropriate for bicycle lane or paved shoulder widths between 0.9 and 2.4 m and curb lane widths between 3.0 and 5.6 m.

Variables that increase the BCI and thus have a negative effect on the comfort level of bicyclists include speed, volume, and on-street parking. In each example that follows, it is assumed that, with the exception of the variable under consideration (e.g., on-street parking), all other variables in the model are being held constant. With respect to the

Table 9. Ranges of variables included in the regression model.

Variable	Description	Minimum	Maximum
CLW	Curb Lane Width	3.0 m	5.6 m
BLW	Bicycle Lane/Paved Shoulder Width	0.9 m	2.4 m
CLV	Curb Lane Volume	90 vph	900 vph
SPD	85th Percentile Speed	40 km/h	89 km/h

latter, the presence of on-street parking (**PKG**) increases the BCI by 0.506, indicating a high degree of discomfort by bicyclists having to pass parked vehicles. As the speed of motor vehicle traffic increases (**SPD**), so does the BCI value; for each km/h increase in the 85th percentile speed, the index increases by 0.022. This same pattern is true with respect to traffic volume; for each 100 vehicles per hour (vph) increase in volume in the curb lane (**CLV**), the BCI increases by 0.20. On multilane roads, a similar increase in same-direction volume in lanes other than the curb lane (**OLV**) increases the BCI by 0.04.

Model sensitivity

To better understand the effects that changes in the variables within the model can have on the BCI value, an example is provided in table 10 and described below. A condition that is typical in an urban environment has been established as the baseline condition. This particular street segment is a two-lane road in a commercially developed area with a peak-hour volume of traffic in the curb lane equivalent to 250 vph. The lane widths are 3.4 m, and the 85th percentile speed of traffic along this segment is 56 km/h. Under these conditions, the BCI is 3.68. If this same street were in a residentially developed area, the BCI would be 3.42 or 7.2 percent less. If this street segment contained on-street parking, the BCI would be 4.19 or 13.8 percent greater. If the segment were a multilane street with comparable volumes in the lanes other than the curb lane, the index increases by just 1.6 percent to 3.74.

Changes or improvements to the baseline conditions of the roadway segment in terms of motor vehicle speeds, traffic volumes, and lane widths can also dramatically change the BCI. As shown in table 10, an increase in the lane width of 0.3 m decreases the index by 4.1 percent to 3.53. Similar reductions can be achieved by reducing the 85th percentile speeds by 8 km/h or the traffic volume by 100 vph. The most dramatic effect occurs with the addition of a 1.2-m bicycle lane to the existing facility; this change reduces the BCI value by almost 40 percent to 2.22.

Special circumstances

During the pilot phase of this study, several variables other than those traditionally thought of as important (e.g., lane width, speed , and volume) were identified as being important to the comfort level of bicyclists. These variables included the presence of heavy trucks or buses, vehicles turning right into driveways, and vehicles pulling into or out of on-street parking spaces. As a result, several video clips illustrating these special circumstances were included in the survey.

The clips illustrating these scenarios were taken from the same roadways for which representative clips had been previously selected for inclusion in the survey. Thus, comfort level ratings were obtained for the representative clip and for the clip showing the special circumstances of interest. The analysis focused on the differences in the ratings between the "representative" clips and the "special circumstances" clips. The results (*see figure 14*) showed that all three

Table 10. Example of the effects of variable changes within the Bicycle Compatibility Index (BCI) model.

Base Condition: Two-lane street in commercially developed area with 3.4-m lanes, 85th percentile speeds of 56 km/h, and curb lane traffic volumes of 250 vehicles per hour (vph)										
Change/Condition	**BL**	**CLW**	**BLW**	**PKG**	**SPD**	**CLV**	**OLV**	**AREA**	**BCI**	**% Change**
Base Condition	0	3.4	0	0	56	250	0	0	3.68	--
Increase lane width by 0.3 m	0	3.7	0	0	56	250	0	0	3.53	-4.1
Decrease volume by 100 vph	0	3.4	0	0	56	150	0	0	3.48	-5.4
Decrease speed by 8 km/h	0	3.4	0	0	48	250	0	0	3.52	-4.7
Add on-street parking	0	3.4	0	1	56	250	0	0	4.19	+13.8
Same street in residential area	0	3.4	0	0	56	250	0	1	3.42	-7.2
Multilane street w/ OLV=150 vph	0	3.4	0	0	56	250	150	0	3.74	+1.6
Add a 1.2-m bicycle lane	1	3.4	1.2	0	56	250	0	0	2.22	-39.6

special circumstances studied produced higher overall mean comfort level ratings (indicating a lower level of comfort) when compared with the representative conditions. The circumstance that resulted in the largest increase in the mean rating (0.60 increase for the group containing **all** bicyclists) was vehicles pulling into or out of on-street parking spaces. The effect of large trucks or buses resulted in a very similar increase of 0.50 for **all** bicyclists. The scenario showing the least effect, but still significant, was vehicles turning right into driveways. This situation resulted in an increase of 0.1 for **all** bicyclists.

The results in figure 14 are also shown for each of the three groups of bicyclists. For the scenarios of large trucks/buses and right-turning vehicles, there are virtually no differences in the changes in mean ratings between the groups. In other words, the effect of these two special circumstances on comfort level is similar, regardless of experience level. However, for vehicles pulling into or out of parking spaces, there are significant differences between the groups of bicyclists, with casual riders being the least comfortable of the three groups (0.9 increase in the overall mean comfort level rating compared with 0.7 and 0.5 for experienced recreational and experienced commuter bicyclists, respectively). As discussed in the previous section, the use of the index value for **all** bicyclists is most appropriate unless it is known that the large majority of bicyclists using a given facility are indeed, for example, casual bicyclists.

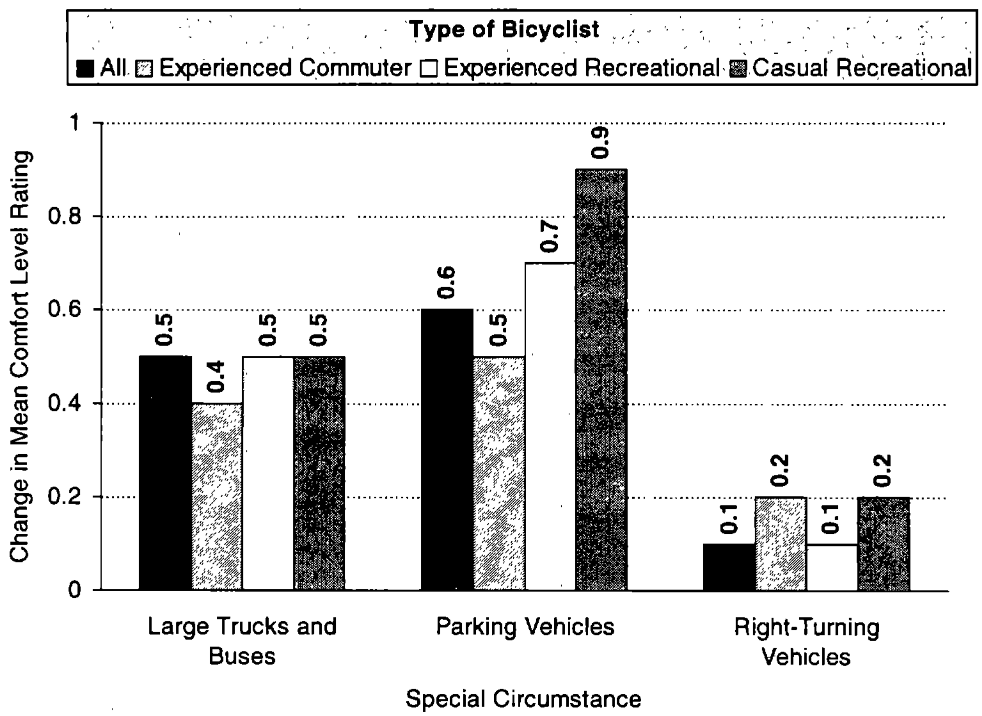


Figure 14. Change (increase) in the overall mean comfort level ratings by type of bicyclist for the special circumstances evaluated in the video survey.

Overall, the results from these special circumstances indicate that bicyclists are impacted by each of these scenarios to varying degrees. Thus, if the roadway segment being evaluated has a significant number of large trucks or buses, or a high volume of right-turning vehicles, or a high number of vehicles pulling into or out of on-street parking spaces, the BCI should be adjusted to account for these situations. While the sample of sites with these special conditions provided evidence of the effect on the comfort level of bicyclists, the range of operational and geometric characteristics over which these conditions were evaluated did not allow for analytical development of adjustment factors.

Instead, a more qualitative approach was taken to develop adjustment factors for each of the three variables. The first step in this approach was to examine the volume of events (e.g., number of large trucks or buses) shown to the participants during the 40-s video clips and determine if the volume could be considered high, low, or somewhere in between. The theory here is that the volume of events will be correlated with an increase in the mean comfort level rating. For example, if the number of large trucks (or buses) seen in the 40-s video clip can be considered a high volume of trucks, then the increase in the mean comfort level rating shown in the analysis (i.e., 0.50 for **all** bicyclists) would be the maximum adjustment factor applied to the BCI model. For truck volumes lower than those included in the video clips, smaller adjustment factors could then be developed.

The first variable to which this approach was applied was the presence of large trucks or buses. The number of trucks traveling in the curb lane during the 40-s video clips illustrating this condition was, on average, 1.7; this equates to 153 trucks/h in the curb lane, which can be considered a high volume of trucks for urban/suburban streets.

Another means of expressing this effect is in terms of passing interactions; 153 trucks/h equates to a truck passing a bicyclist, on average, every 24 s, which is quite often. In fact, a truck passing a bicyclist every 30 s or less (equivalent to 120 trucks or more per hour) might be considered extremely uncomfortable for a bicyclist. Thus, the increase in the mean overall comfort level rating of 0.50 should be considered the maximum adjustment factor for large truck/bus presence and applied when the volume of trucks is 120/h or more. On the other end of the scale, a truck passing a bicyclist less often than once every 6 min, on average, equivalent to less than 10 trucks/h, could be considered a non-factor (relative to the other roadway conditions) in terms of the comfort level of a bicyclist. For this low level of truck volume, no adjustment factor should be applied to the BCI model. By interpolating between these two extremes for average time between bicycle/truck interactions, a series of truck adjustment factors based on interaction times and equivalent hourly truck volumes in the curb lane has been developed, as shown in table 11.

For roadways with on-street parking, the issue related to comfort level is the frequency of parking turnover. The video clips in which vehicles were pulling into or out of parking spaces showed, on average, 1.5 vehicles performing such a maneuver over the 40-s period; this equates to 135 vph pulling into or out of on-street parking spaces. This number represents an extremely high parking turnover rate, and thus the increase in the mean overall comfort level rating of 0.6 for parking conditions should be the maximum adjustment that needs to be made for parking turnover. In most cases, parking turnover is directly correlated with the time limits placed on parking spaces and typically, the shortest duration of on-street parking that is found is 15 min. Thus, if the duration of parking allowed is 15 min or less, an adjustment factor of 0.60 should be used. On the other end of the scale, if the parking duration allowed is more than 8 h, there will be very little turnover; thus, no adjustment should be made to the BCI value. By interpolating between these two extremes, adjustment factors were developed for parking turnover for sites with on-street parking, as shown in table 12.

Finally, the video clips showing right-turning vehicles averaged three vehicles turning right in 40 s; this equates to 270 right-turning vehicles in an hour which, again, is a relatively high number. Since the increase in the overall mean comfort level rating for this particular variable was only 0.10 for all bicyclists, the adjustment factor will be equal to that value and applied only when right-turn volumes into driveways or minor intersections along a midblock segment are equal to or greater than 270 vph.

Table 11. Adjustment factors for large truck volumes.

Average Time between Truck/Bicycle Interactions (min)	Hourly Curb Lane Large Truck Volume	Increase the BCI by
≤ 0.5	≥ 120	0.50
0.51 - 1.0	60 - 119	0.40
1.1 - 2.0	30 - 59	0.30
2.1 - 3.0	20 - 29	0.20
3.1 - 6.0	10 - 19	0.10
> 6.0	< 10	0.00

Level of service criteria

Presently, the ***Highway Capacity Manual*** does not define level of service (LOS) criteria for bicycles. For other modes of transportation, however, the term LOS is used to characterize the operational conditions of a roadway with six designations (LOS A through LOS F). The descriptive terms in the written

Table 12. Adjustment factors for on-street parking turnover.

Parking Time Limit (min)	Increase the BCI by
≤ 15	0.60
16 - 30	0.50
31 - 60	0.40
61 - 120	0.30
121 - 240	0.20
241 - 480	0.10
> 480	0.00

definition of LOS include speed and travel time, comfort/convenience, traffic interruptions, and freedom to maneuver. While this concept and the subsequent defining terms were originally developed for motor vehicle applications, the qualitative descriptors of comfort/convenience and freedom to maneuver are most applicable to bicyclists traveling on the roadway in the presence of motor vehicles.

The LOS definition also states that it is the user's perception of the operational conditions within the traffic stream that dictates the ranges of qualitative measures included in each LOS designation. The perceived comfort level of bicyclists within a given set of operating conditions on the roadway is exactly what the BCI model produces. Thus for bicycle LOS, the measure of effectiveness (MOE) should be the BCI. Subsequently, each LOS designation should be defined by a range of values produced by the model. To remain consistent with the ***Highway Capacity Manual***, six LOS designations (A through F) should be defined. A discussion of how these ranges were developed follows.

As a starting point, the distribution of overall mean comfort level ratings (averaged across **all** subjects) by site was examined. The site with the lowest rating produced a mean of 1.24; the site with the highest rating resulted in a mean of 5.49. The conditions included in the video survey and rated by the participants included a broad range of conditions. These sites were selected to range from environments that would be comfortable for every adult bicyclist to those that would not be comfortable for even the most experienced commuter bicyclist. Likewise, the participants in the study ranged from the very timid casual bicyclist who might ride once a month and only on off-street facilities to the most savvy experienced commuter who rode every single day in all types of traffic conditions. With this in mind, the extreme values noted above (1.24 and 5.49) are believed to represent the extremes that might be expected in practice. Shown in figure 15 is a line drawn between these two extreme points, which approximates the distribution of participant scores. On the lower end of the scale, the extreme value of 1.24 represents the point at which virtually all bicyclists feel comfortable riding under a given set of roadway conditions. On the upper end, the extreme value of 5.49 represents the opposite, i.e., the point at which virtually no bicyclists feel comfortable riding. In between these extremes, percentiles along the line can then be selected and used to represent the breakpoints between the various LOS designations. While the selection of these breakpoints is arbitrary (as are the breakpoints used in the ***Highway Capacity Manual*** for other LOS designations), they have been chosen to reflect the full range of site conditions and bicycling experience levels present in most urban and suburban areas.

The 50th percentile along the line corresponds to a mean overall rating of 3.40. Since there are six levels of service (A through F), the rating corresponding to the 50th percentile (3.40) was selected as the breakpoint in the middle of the scale

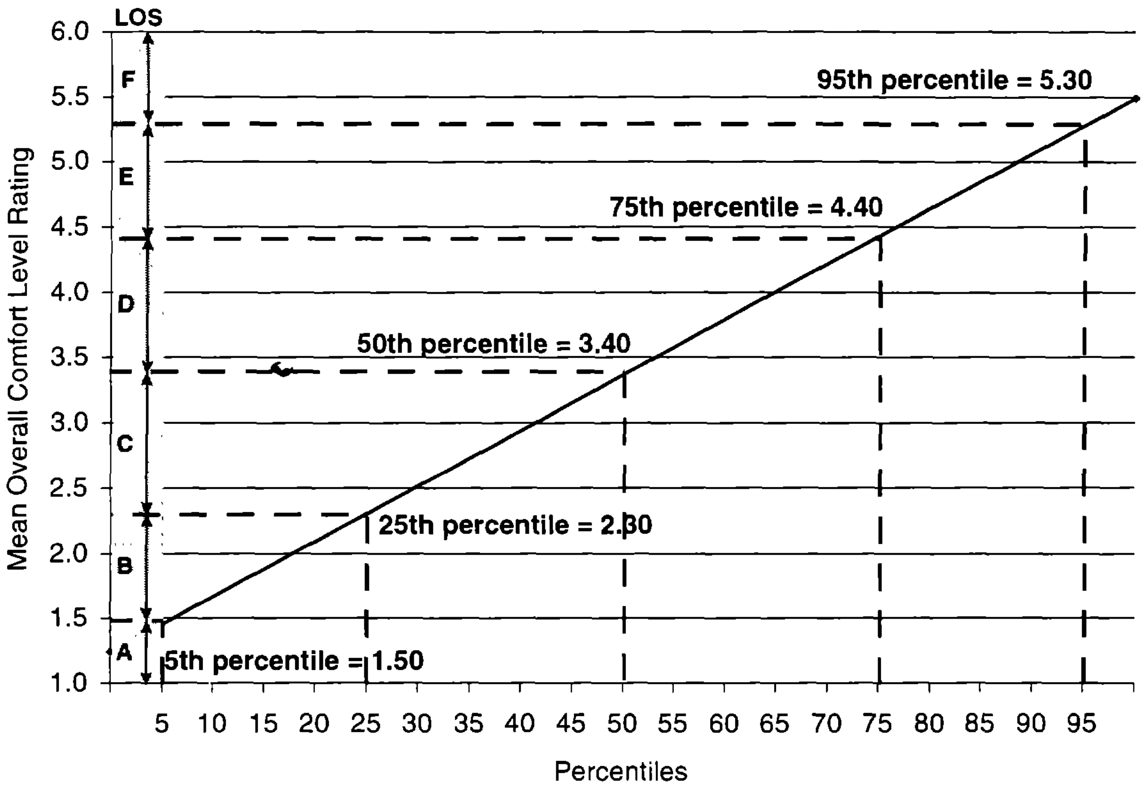


Figure 15. Distribution of mean overall comfort level ratings used in establishing level of service (LOS) designations.

between LOS C and LOS D (*see table 13*). The breakpoints between the other levels were selected to reflect a slightly greater concentration of scores surrounding the 50th percentile and a very low concentration at the extremes. Extending 25 percent from either side of the 50th percentile results in a 75th percentile along the line corresponding to a mean overall rating of 4.40 and a 25th percentile corresponding to a value of 2.30. These values were selected as the breakpoints between LOS D and LOS E, and LOS C and LOS B, respectively.

To define the breakpoint between LOS E and LOS F, the 95th percentile was selected. From figure 15, this percentile corresponds to the mean overall rating of 5.30. On the other end of the scale, the 5th percentile was selected as the breakpoint between LOS A and LOS B, equivalent to a mean overall rating of 1.50. **Note, the LOS designations were established using the BCI model for all bicyclists (*see table 8*). It is not appropriate to use the results from models for specific experience**

Table 13. Bicycle Compatibility Index (BCI) ranges associated with level of service (LOS) designations.

LOS Designation	BCI Range
A	≤ 1.50
B	1.51 - 2.30
C	2.31 - 3.40
D	3.41 - 4.40
E	4.41 - 5.30
F	> 5.30

levels (i.e., experienced commuter vs. experienced recreational vs. casual recreational) with these LOS designations. A more complete discussion of how to use these LOS designations in cases where it is known that the majority of bicyclists using a particular route are indeed "casual" is provided in chapter 6.

Chapter 5 Intersection pilot study

The secondary objective of this research effort was to apply the video methodology used for rating midblock roadway segments to intersections and assess whether such an approach was valid for rating the bicycle compatibility of intersections. The goal of this limited effort was not to completely develop a BCI model for intersections but rather to determine if the video technique showed promise for application to intersections. Thus, the scope of this pilot study for intersections was limited to one maneuver that bicyclists typically make at an intersection. The maneuver selected was a bicyclist traveling straight through an intersection in the presence of right-turning traffic (*see figure 16*).

Site selection

The sites selected for the intersection study were located in several of the same cites as the selected roadway segments. As with the midblock roadway segments, a matrix (*see table 14*) that stratified several of the geometric and operational variables was developed to ensure that the sites selected represented the range of variables a bicyclist may encounter in performing this maneuver in an urban or suburban environment. The ***bicycle lane facilities*** were separated from the ***standard/wide curb lane facilities*** and the right-turn traffic volumes were separated into two categories. Another stratification variable used for those facilities with a bicycle lane on the approach was whether or not the bicyclist had to shift to the left, across an auxiliary right-turn lane, to travel straight through the intersection. The

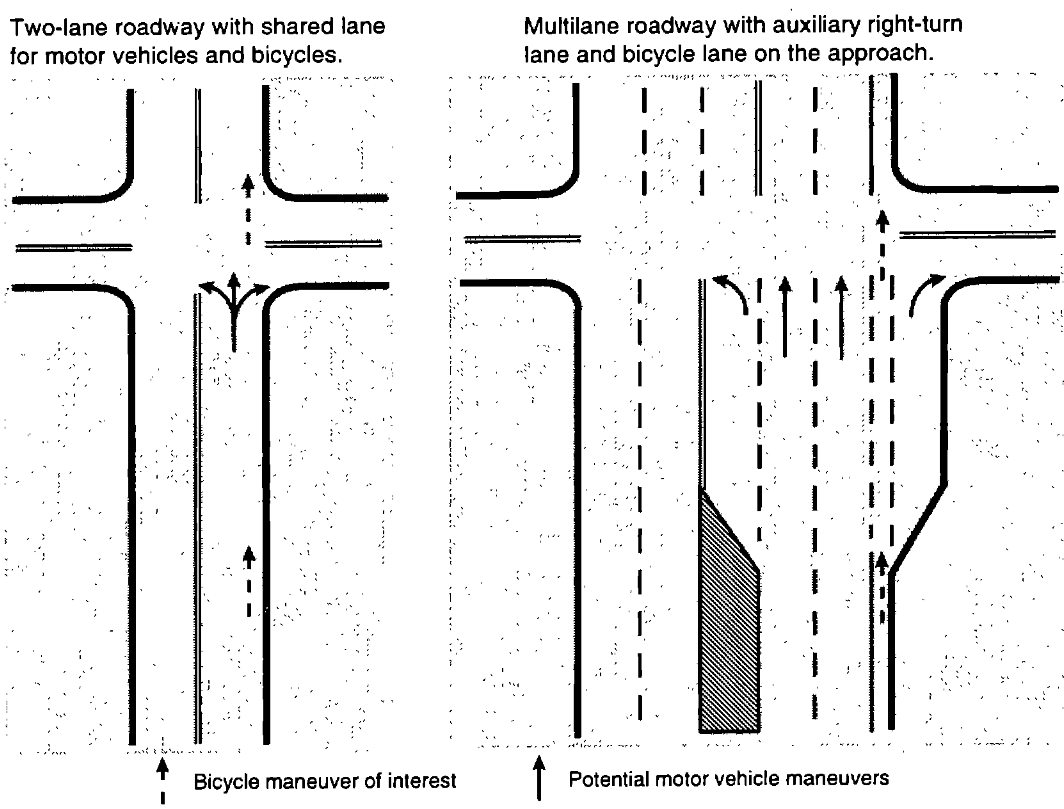


Figure 16. The maneuver selected for evaluation of the use of the video methodology at intersections was the bicyclist traveling straight through the intersection in the presence of right-turning traffic.

number of sites selected in each of the cells is shown in table 14, with the total number being 19. Shown in figure 17 are four of the intersection sites illustrating the range of conditions included in the evaluation.

Data collection

The procedures followed for collecting data for the intersection locations were similar to those followed for the midblock roadway segments (*see chapter 3*). The one exception pertained to the filming of the intersection. For the midblock locations, the camera was positioned along a tangent section of roadway, aimed parallel to the roadway, and set to "record" passing traffic conditions for 15 min. At the intersection, the camera had to be positioned upstream of the intersection at a point that would allow participants to observe the speed of approaching traffic as well as the lane-changing behavior of traffic into auxiliary right-turn lanes (*see figure 18*). In some cases, the auxiliary lanes were extremely long. With the camera positioned upstream of the beginning of the auxiliary lane, it made viewing the detailed configuration of the intersection difficult (*see figure 19*). Thus, at the start of filming for each location, the camera was zoomed out to show a close-up of the intersection and then slowly zoomed in to the normal (non-zoom) position for the 15 min of filming. This zooming sequence for each intersection was added prior to the 40-s clip used for rating the intersection.

Table 14. Number of sites selected for the intersection study stratified by right-turn volume and type of approach lane.

Right-Turn Volume (vph)	Type of Approach Lane		
	Standard/Wide Curb Lane	Bicycle Lane	
		Shift Left [1]	Straight
≤ 270	3	2	4
> 270	4	4	2

[1] Sites in these cells were designed such that the through bicyclist had to shift to the left, across an auxiliary right-turn lane, to travel straight through the intersection.

Video production

The production of the video for the survey followed the same procedures described in chapter 3 for the production of the video for the midblock roadway segments. The only difference was in the volume counted and used to select representative video clips. For the midblock locations, the traffic volume of interest was the curb lane volume; for the intersection locations, it was the right-turning traffic volume. Thus, the equation used in conjunction with the right-turn volume counts for selecting representative intervals was as follows:

$$V_{rt} = (V_{trt}/15 \text{ min})(40 \text{ s}/60 \text{ s})$$

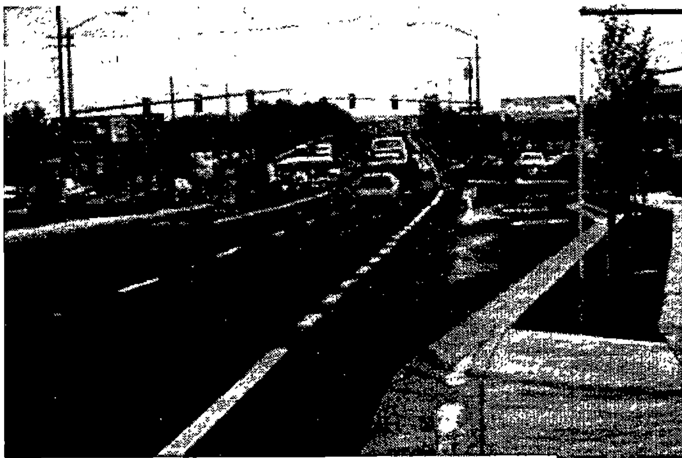
where:

V_{rt} = representative right-turn volume for the 40-s interval, and

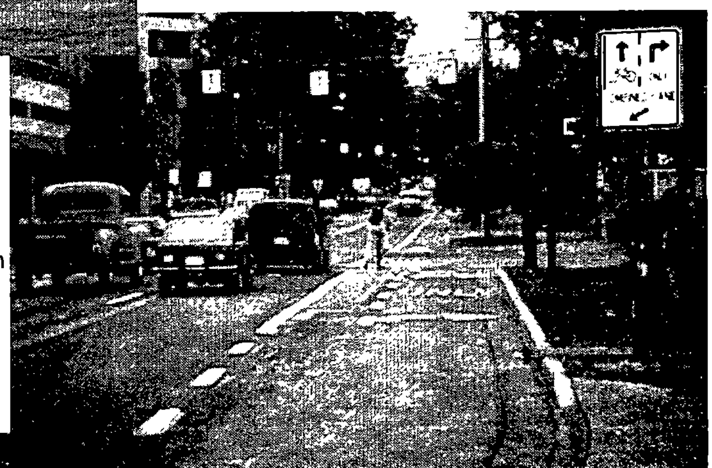
V_{trt} = total right-turn volume observed during the 15 min of videotape.

Video survey

The video survey for the intersections included the same individuals in the same cities who participated in the roadway segment survey. Once the roadway segment survey was completed each evening, the participants were provided with new rating forms and a new set of instructions (*see appendix C*). They were instructed to rate each of the 19 intersections using the same six-point scale with respect to how comfortable they would be riding a bicycle through the intersection shown in the presence of the right-turning traffic and the other conditions shown.



High-volume, high-speed intersection with channelized right-turn lane and bicycle lane on the approach.



High-volume, low-speed intersection with unique combined right-turn/bicycle lane.

Low-volume, low-speed intersection with bicycle lane separated from motor-vehicle lanes by wide-dashed striping.

Low-volume, low-speed intersection with typical shared through and right-turn lane for motor vehicles (i.e., no separate right-turn lane) and no bicycle lane.

Figure 17. Examples of sites included in the intersection pilot study.

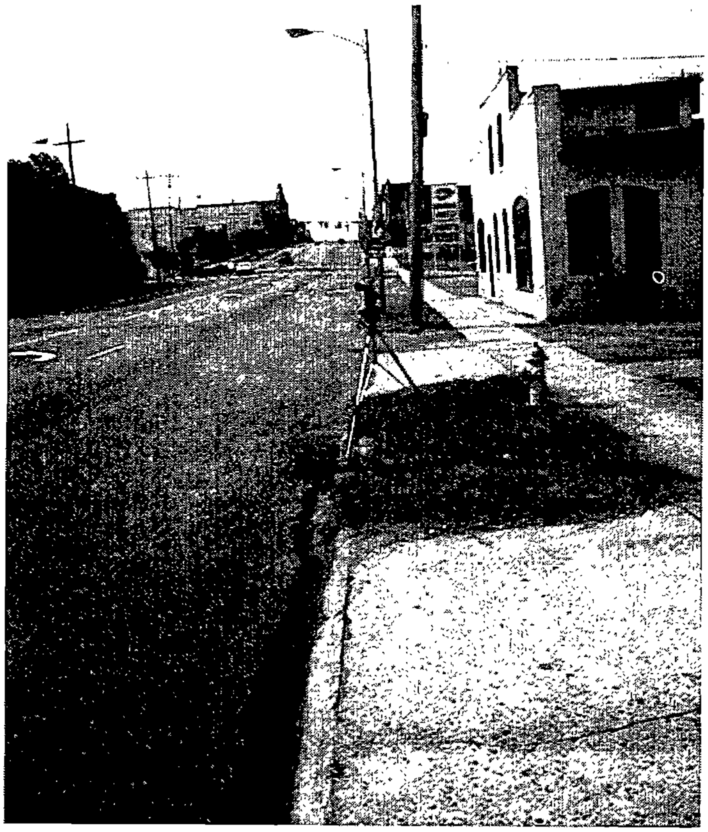


Figure 18. For the intersection study, the camera was positioned upstream of the intersection to allow participants to observe the approach speeds and lane-changing behaviors of motorists.

The variables for which ratings were provided differed for approximately half of the participants. It had been hypothesized in the early stages of the study that the participants would make one overall comfort level rating, and that the significant geometric and operational variables would be reflected in that rating. This approach differed from that of having the participants provide not only an overall rating, but ratings for other variables believed to be important in terms of assessing the bicycle compatibility of an intersection. In the latter case, it was possible that the overall rating was influenced by the rating of one or more of the other variables.

Using these two approaches, an additional experiment was carried out within this intersection study. Approximately half of the participants provided a single overall comfort level rating for the bicycle maneuver in question. The remaining participants provided not only an overall rating, but also comfort level ratings based on four other factors. These factors included the volume of right-turning traffic, the speed of approaching traffic, the width or space available to them to maneuver through the intersection, and the clarity of signs and markings to guide the motorist and bicyclist through the intersection.

Data analysis

The analysis of the video survey data focused on the development of a model to predict the bicycle compatibility of intersections with respect to the maneuver selected for this pilot study. The objective of the analysis was to determine if the video methodology could be applied at intersections and produce results that could be used to assess the bicycle compatibility of intersections.

Differences in overall comfort level ratings between subjects were examined by computing an average overall rating score (across intersections) for each subject. A regression tree model was then developed using the CART (Classification And Regression Tree) procedure to identify subgroups of subjects over which the overall ratings differed consistently.[10] Independent variables in this model included the questionnaire item responses and a variable indicating whether or not the subject provided a single overall rating or an overall rating plus the other four ratings.

The results of this analysis were quite consistent with those of the midblock analysis in that the primary subdivision of subjects was between those who made a large percentage of their trips for commuting purposes on major city streets versus those who primarily rode for recreation largely on more minor streets with less traffic and lower speeds or on bicycle paths. The average comfort ratings for these two groups were 3.49 and 4.10, respectively. It was also of interest to note that consistent differences in overall scores were not found between those subjects who provided the single overall rating versus those who also provided the additional ratings.

As with the roadway segment analysis, regression models were used to investigate relationships between intersection characteristics and comfort level ratings. The geometric and operational variables collected in the field or from the video and included in the regression modeling are shown in table 15. To estimate the effects of these characteristics on the overall comfort level ratings, means and variances of the overall ratings were computed for each intersection across all subjects. A weighted regression model, where each case was weighted by the inverse of its variance, was then developed using the mean overall rating as the response variable and the intersection characteristics as independent variables. Using combinations of the independent variables and eliminating all variables and combinations that were not significant at the $p \leq 0.01$ level, the resulting regression model is expressed as follows:

$$BCI_{(INT)} = 2.22 - 0.76\mathbf{BL} + 0.49\mathbf{SHIFT} + 0.003\mathbf{RVOL} + 0.001\mathbf{TVOL}$$

The variable having the greatest impact on the index was the presence or absence of a bicycle lane approaching the intersection. If a bicycle lane (**BL**) is present, the index is reduced by 0.76, indicating a higher level of comfort. Another of the significant variables was **SHIFT**, which indicates if the bicyclist had to shift to the left across an auxiliary lane to continue straight through the intersection. If this scenario exists (*see example in figure 20*), the index increases by almost half a point (0.49), indicating that bicyclists are less comfortable when this maneuver is required. The other significant variables were the right-turn volume (**RVOL**) and the total approach volume (**TVOL**); both of these variables increase the index as volumes increase, again indicating a decrease in the comfort level of bicyclists with higher traffic volumes. For each 100-vph increase in right-turn volumes, the index

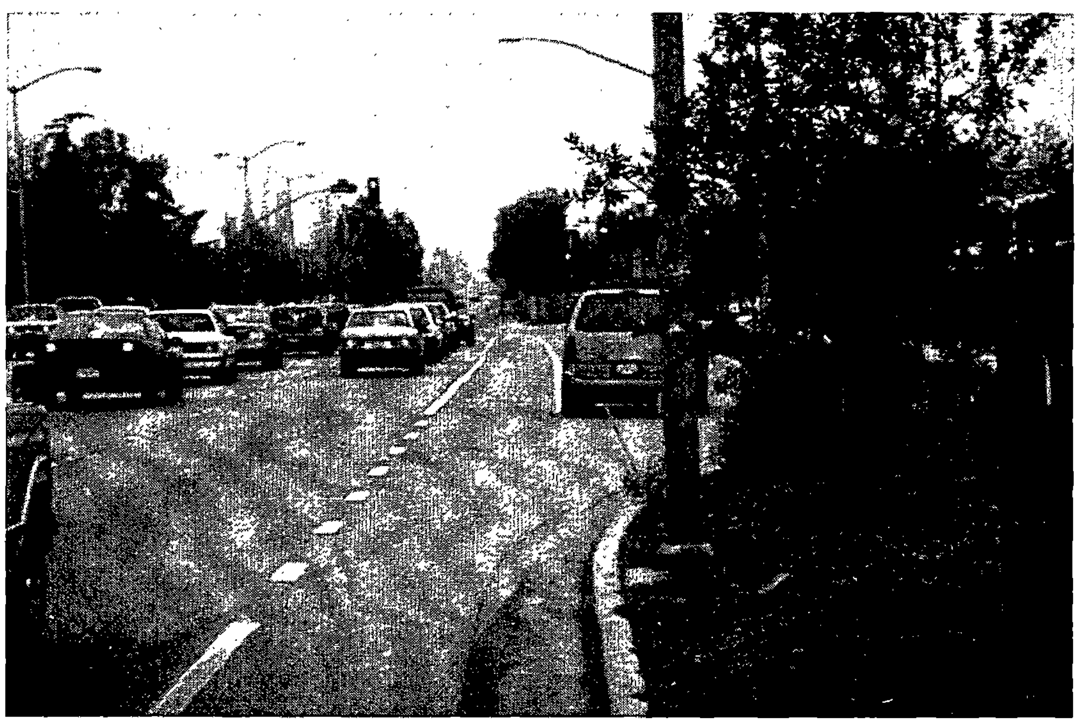


Figure 19. Sites with high volumes of right-turning traffic sometimes contained extremely long auxiliary turn lanes, which made viewing the intersection proper difficult.

Table 15. Variables included in the regression modeling analysis of intersections.

Variable Name	Description	Variable Codes/Units
NL	Number of through lanes in the direction of travel	One direction (1 or 2)
DT	Number of travel directions	One-way street = 1 Two-way street = 2
BL	Presence of a bicycle lane approaching the intersection	No = 0 Yes = 1
BP	Presence of a bicycle pocket at the intersection	No = 0 Yes = 1
SHIFT	Need for bicyclist to shift left across an auxiliary right-turn lane to continue straight through the intersection	No shift required = 0 Shift required = 1
RTL	Type of right-turn lane	1= Shared lane 2 = Non-channelized auxiliary lane 3 = Non-channelized right-turn-only lane 4 = Non-channelized right-turn-only/bicycle lane combination 5 = Channelized auxiliary lane
SPD	85th percentile approach speed	Km/h
RVOL	Right-turn volume	Hourly volume

increases by 0.30; for each such increase in total approach volumes, the index increases by 0.10.

The model developed had an R^2-value of 0.81, indicating that 81 percent of the variance in the index value is explained by the four variables included in the equation. Thus, the use of these four variables can produce an index value that is a reliable predictor of a bicyclist's comfort level with performing the maneuver studied, i.e., continuing straight through the intersection in the presence of right-turning traffic. It appears then that this model is a good indicator of the bicycle compatibility of an intersection for that particular maneuver. These results also indicate that the use of the video methodology at intersections can be a reliable means of developing a compatibility index for intersections. However, more research is needed to fully develop an intersection index, including an expansion of the scope of bicycle maneuvers and intersection characteristics.

Figure 20. The intersection index increased significantly (indicating a lower level of comfort) if the bicyclist was required to shift to the left to proceed straight through the intersection.

Chapter

6

Summary & conclusions

Summary of results

The primary objective of this research effort was to develop an instrument that would allow bicycle coordinators, transportation planners, traffic engineers, and others to evaluate the capability of specific roadways in their communities to accommodate both motorists and bicyclists. The tool developed is the bicycle compatibility index (BCI), which incorporates the geometric and operational variables considered by adult bicyclists to be important in terms of their comfort level when riding on streets in the presence of motor vehicle traffic. ***Note: The BCI model is not necessarily appropriate for evaluating the compatibility of roadways for youth bicyclists.***

The approach used in developing the BCI was to obtain the perspectives of bicyclists by having them view numerous roadway segments captured on videotape and rate those segments with respect to how comfortable they would be riding there under the geometric and operational conditions shown. The reliability of the results obtained using this video technique of data collection with respect to reflecting on-street comfort levels was validated in a pilot study (*see chapter 2*). The procedure used offered several advantages over other forms of data collection, including minimizing the risk to bicyclists, maximizing the range of roadway conditions to which the bicyclists could be exposed, and controlling the variables evaluated by the bicyclists.

Using the perspectives of over 200 study participants in three locations (Olympia, WA; Austin, TX; and Chapel Hill, NC), the BCI model was developed for all bicyclists, as shown in table 16 (*see appendix D for the equivalent English units version of the model*). This model predicts the overall comfort level rating of a bicyclist using the eight significant (at $p \leq 0.01$) variables shown and an adjustment factor (**AF**) to account for three additional operational characteristics. The basic model (excluding the adjustment factor) has an R^2-value of 0.89, indicating that 89 percent of the variance in the index or comfort level of the bicyclist is explained by the eight variables included in the model. In other words, the model is a reliable predictor of the expected comfort level of bicyclists on the basis of these eight variables describing the geometric and operational conditions of the roadway. The variable with the largest effect on the index is the presence or absence of a bicycle lane or paved shoulder that is at least 0.9 m wide (**BL**); the presence of a bicycle lane (paved shoulder) reduces the index by almost a full point, indicating an increased level of comfort for the bicyclist. Increasing the width of the bicycle lane or paved shoulder (**BLW**) or the curb lane (**CLW**) also reduces the index as does the presence of residential development along the roadside (**AREA**). On the other hand, an increase in traffic volume (**CLV** and **OLV**) or motor vehicle speeds (**SPD**) increases the index, indicating a lower level of comfort for the bicyclist. The presence of on-street parking (**PKG**) also increases the index.

In addition to the primary variables included in the BCI model, three additional variables defining specific operating conditions were also examined. These supplemental variables were identified during the pilot phase of the study as having a potential impact on the comfort level of bicyclists and included the presence of: 1) large trucks or buses, 2) vehicles turning right into driveways or minor intersections,

Table 16. Bicycle Compatibility Index (BCI) model, variable definitions, and adjustment factors.

$$\mathbf{BCI} = 3.67 - 0.966\mathbf{BL} - 0.410\mathbf{BLW} - 0.498\mathbf{CLW} + 0.002\mathbf{CLV} + 0.0004\mathbf{OLV} + 0.022\mathbf{SPD} + 0.506\mathbf{PKG} - 0.264\mathbf{AREA} + \mathbf{AF}$$

where:

BL = presence of a bicycle lane or paved shoulder ≥ 0.9 m
no = 0
yes = 1

BLW = bicycle lane (or paved shoulder) width
m (to the nearest tenth)

CLW = curb lane width
m (to the nearest tenth)

CLV = curb lane volume
vph in one direction

OLV = other lane(s) volume - same direction
vph

SPD = 85th percentile speed of traffic
km/h

PKG = presence of a parking lane with more than 30 percent occupancy
no = 0
yes = 1

AREA = type of roadside development
residential = 1
other type = 0

AF = $f_t + f_p + f_{rt}$

where:

f_t = adjustment factor for truck volumes (*see below*)

f_p = adjustment factor for parking turnover (*see below*)

f_{rt} = adjustment factor for right-turn volumes (*see below*)

Adjustment Factors

Hourly Curb Lane Large Truck Volume[1]	f_t
≥ 120	0.5
60 - 119	0.4
30-59	0.3
20-29	0.2
10-19	0.1
< 10	0.0

Parking Time Limit (min)	f_p
≤ 15	0.6
16 - 30	0.5
31 - 60	0.4
61 - 120	0.3
121 - 240	0.2
241- 480	0.1
> 480	0.0

Hourly Right-Turn Volume[2]	f_{rt}
≥ 270	0.1
< 270	0.0

[1] Large trucks are defined as all vehicles with six or more tires.
[2] Includes total number of right turns into driveways or minor intersections along a roadway segment.

or 3) vehicles pulling into or out of on-street parking spaces.

An analysis of the overall comfort level ratings made when viewing video clips illustrating these conditions showed all three of these variables to significantly increase the comfort level rating, thus indicating a lower level of comfort when these conditions were present. For **all** bicyclists, the overall mean rating increased by 0.50 when large trucks or buses were present. When there were vehicles pulling into or out parking spaces, the average rating increased by 0.60. And finally, the presence of right-turning vehicles resulted in an increase in the mean rating of 0.10.

While the presence of these three specific operating conditions was not evaluated across all possible combinations of geometrics and operations, the results of the limited sample do indicate a need for adjustment to the BCI model when large trucks or buses are present, when there is a high number of vehicles pulling into or out of on-street parking spaces, or when there is a high volume of right-turning vehicles. Thus, a series of adjustment factors that can be added to the model have been developed for each of these scenarios (*see table 16*). These factors were developed on the basis of the theory that the conditions shown to the survey participants represented worst-case scenarios and, subsequently, the increase in the overall mean comfort level rating represented the maximum adjustment that would be required (*see chapter 4 for a detailed discussion*).

It should be noted that one variable not included in the development of the BCI model was the grade of the roadway. Results from a preliminary effort showed that changes in grade of 2 percent or less were not distinguishable on the video. The advantages of using video, which included not exposing bicyclists to high-risk conditions, incorporating a much larger sample of sites, and controlling specific variables to ensure that all subjects were exposed to identical conditions, were believed to outweigh the absence of this one variable. It is also believed that the variables having the most significant effect on the bicycle compatibility of a roadway have been included in the BCI model. Specifically, the variables of width, speed, volume, and on-street parking were shown to have the greatest impact on the index. At this time, the impact of grade relative to these and the other significant variables included in the model is unknown but may be determined in future research efforts.

Once the BCI model was developed, bicycle level of service (LOS) criteria were established on the basis of the distribution of the participants' mean comfort level ratings. Currently, there are no LOS criteria provided in the ***Highway Capacity Manual***. However, the definition of the LOS according to the manual is founded on the concept of users' perceptions of qualitative measures that characterize the operational conditions of the roadway. Two of the terms used in the manual to describe LOS are comfort/convenience and freedom to maneuver; both of these terms are applicable to bicyclists and are directly reflected in the BCI since the rating scale used by the study participants was a direct indication of comfort level.

Thus, using the distribution of participant comfort level ratings across all sites included in this study, LOS designations were established for LOS A through LOS F, as shown in table 17. LOS A (represented by an index ≤ 1.50) indicates that a roadway is extremely compatible (or comfortable) for the average adult bicyclist while LOS F (represented by an index > 5.30) is an indicator that the roadway is extremely incompatible (or uncomfortable) for the average adult bicyclist.

In developing the BCI model, several other issues were addressed, including the effect of bicycling experience level on perceived comfort levels. Using the results from a questionnaire completed by the participants, the bicyclists were stratified into three groups based on their riding habits such as number of bicycle trips/wk and types of facilities used (e.g., major roadways vs. bicycle paths). A comparison of the comfort level ratings of these three groups showed that "casual recreational" bicyclists produced a significantly higher overall mean comfort level rating (3.1) across all sites than "experienced recreational" or "experienced commuter" bicyclists (2.7 and 2.6, respectively). As a result of these differences, separate BCI models were produced for each of the three groups in addition to the model for **all** bicyclists (*see table 8 in chapter 4*). However, in real-world applications, it is most likely that bicyclists of all experience levels will ride or have the opportunity to ride on any given segment of roadway. Thus, it is recommended that the BCI model developed for **all** bicyclists and shown in table 16 be used without modification for most applications. **The LOS designations shown in table 17 were developed on the basis of this model and thus, are only applicable to results produced with the "all bicyclists" model.** Thus, use of the model for casual recreational bicyclists or other specific groups of bicyclists in conjunction with these LOS designations is not appropriate.

Instead, a different approach that can be used to ensure that facilities meet the desired comfort levels of casual bicyclists is to simply design for a higher level of service. As noted in chapter 4, the **casual** bicyclist model is likely to result in BCI values that are 0.14 to 0.38 greater than the model for **all** bicyclists. The differences in BCI values between LOS designations are, on average, 1.0 (*see table 17*). By designing for a higher LOS (e.g., LOS B rather than LOS C) on a facility known to produce a high number of casual bicyclists, the necessary comfort level for this group of bicyclists can be achieved with the model for **all** bicyclists. **It should be noted that where casual bicyclists are expected, the facility should always be designed at LOS C or better.**

Another issue addressed was that of possible regional differences in the perceptions of bicyclists. If bicyclists in different geographic regions of the country perceive comfort levels differently, then separate models would need to be developed to reflect these differences. An analysis of the comfort level ratings across subjects in the three survey cities showed no differences in the mean comfort levels for the four variables rated (speed, volume, width, and overall). This lack of differences indicates that the perceptions of individuals with respect to bicycle compatibility are the same in the three regions where the survey was conducted, and that the BCI model should be applicable across all regions of the country.

It is important to note again that the BCI model developed is for midblock street segments only and is primarily intended for

Table 17. Bicycle Compatibility Index (BCI) ranges associated with level of service (LOS) designations and compatibility level qualifiers.

LOS	BCI Range	Compatibility Level[1]
A	≤ 1.50	Extremely High
B	1.51 - 2.30	Very High
C	2.31 - 3.40	Moderately High
D	3.41 - 4.40	Moderately Low
E	4.41 - 5.30	Very Low
F	> 5.30	Extremely Low

[1] Qualifiers for compatibility level pertain to the average adult bicyclist.

use on "through" streets. In other words, the ratings do not account for major intersections along the route where the bicyclist may encounter a stop sign or traffic signal. A secondary objective of this research effort was to apply the developed methodology used for rating midblock roadway segments to intersections and assess whether such an approach was valid for rating the bicycle compatibility of intersections. In a limited effort, bicyclists were asked to rate a series of intersections with respect to how comfortable they were riding through the intersection in the presence of right-turning traffic. The relationship between these ratings and the geometric and operational conditions of the intersection was determined through regression modeling. By including only those variables or combinations of variables that were significant (at $p \leq 0.01$), the following model ($R^2 = 0.81$) was developed:

$$BCI_{(INT)} = 2.22 - 0.76\mathbf{BL} + 0.49\mathbf{SHIFT} + 0.003\mathbf{RVOL} + 0.001\mathbf{TVOL}$$

Similar to the BCI model for midblock segments, the variable having the greatest impact was the presence or absence of a bicycle lane (**BL**) on the approach to the intersection. The presence of such a lane dramatically reduces the index value, indicating a higher level of comfort. The remaining variables in the model all produce increases in the index, indicating a lower level of comfort, with the most significant of these conditions being when a bicyclist has to shift to the left across an auxiliary right-turn lane to proceed straight through the intersection.

Overall, the results of this limited effort for intersections was positive and showed that the video methodology used to obtain bicyclists' perspectives can be a reliable means for producing a compatibility index for intersections. However, future research needs to be conducted in which the scope of the study is expanded to include the full range of possible intersection maneuvers by bicyclists and the full range of geometric and operational conditions that can be expected in urban/suburban settings.

Conclusions

The BCI model and the subsequent LOS designations provide bicycle coordinators, transportation planners, traffic engineers, and others the capability to assess their roadways with respect to compatibility for shared-use operations by motorists and bicyclists. The tool also allows practitioners to better plan for and design roadways that are bicycle compatible. Specifically, the BCI model can be used for the following applications:

- Operational Evaluation - Existing roadways can be evaluated using the BCI model to determine the bicycle LOS present on all segments. This type of evaluation may be useful in several ways. First, a bicycle compatibility map can be produced for the bicycling public to indicate the LOS they can expect on each roadway segment. Second, roadway segments or "links" being considered for inclusion in the bicycle network system can be evaluated to determine which segments are the most compatible for bicyclists. In addition, "weak links" in the bicycle network system can be determined, and prioritization of sites needing improvements can be established on the basis of the index values. Finally, alternative treatments (e.g., addition of a bicycle lane vs. removal of parking) for improving the bicycle compatibility of a roadway can be evaluated using the BCI model.

- Design - New roadways or roadways that are being re-designed or retrofitted can be assessed to determine if they are bicycle compatible. The planned geometric parameters and predicted or known operational parameters can be used as inputs to the model to produce the BCI value and determine the bicycle LOS that can be expected on the roadway. If the roadway does not meet the desired LOS, the model can be used to evaluate changes in the design necessary to improve the bicycle LOS (*see example below*).

- Planning - Data from long-range planning forecasts can be used to assess the bicycle compatibility of roadways in the future using projected volumes and planned roadway improvements. The model provides the user with a mechanism to quantitatively define and assess long-range bicycle transportation plans.

Application example

Provided below is a brief example of how the BCI model can be applied in the assessment of design alternatives for a roadway that is being planned for reconstruction. A minor arterial that connects a suburban area to the major arterial used for commuting into and out of downtown is being widened from two lanes to four because of a projected increase in volumes. The development along the roadside is a combination of retail businesses and light commercial industries. The current average annual daily traffic (AADT) on the roadway is 10,000 vehicles per day (vpd) with 2 percent truck traffic, and the projected AADT in five years is 16,000 vpd with the same percentage of trucks. Motor vehicle speeds on the facility currently have an 85th percentile of 50 km/h; with the additional lanes, this value is expected to increase slightly to 55 km/h. The original proposed highway department design (*see figure 21*) within the 20.0-m right-of-way included 3.6-m wide lanes, a 1.0-m

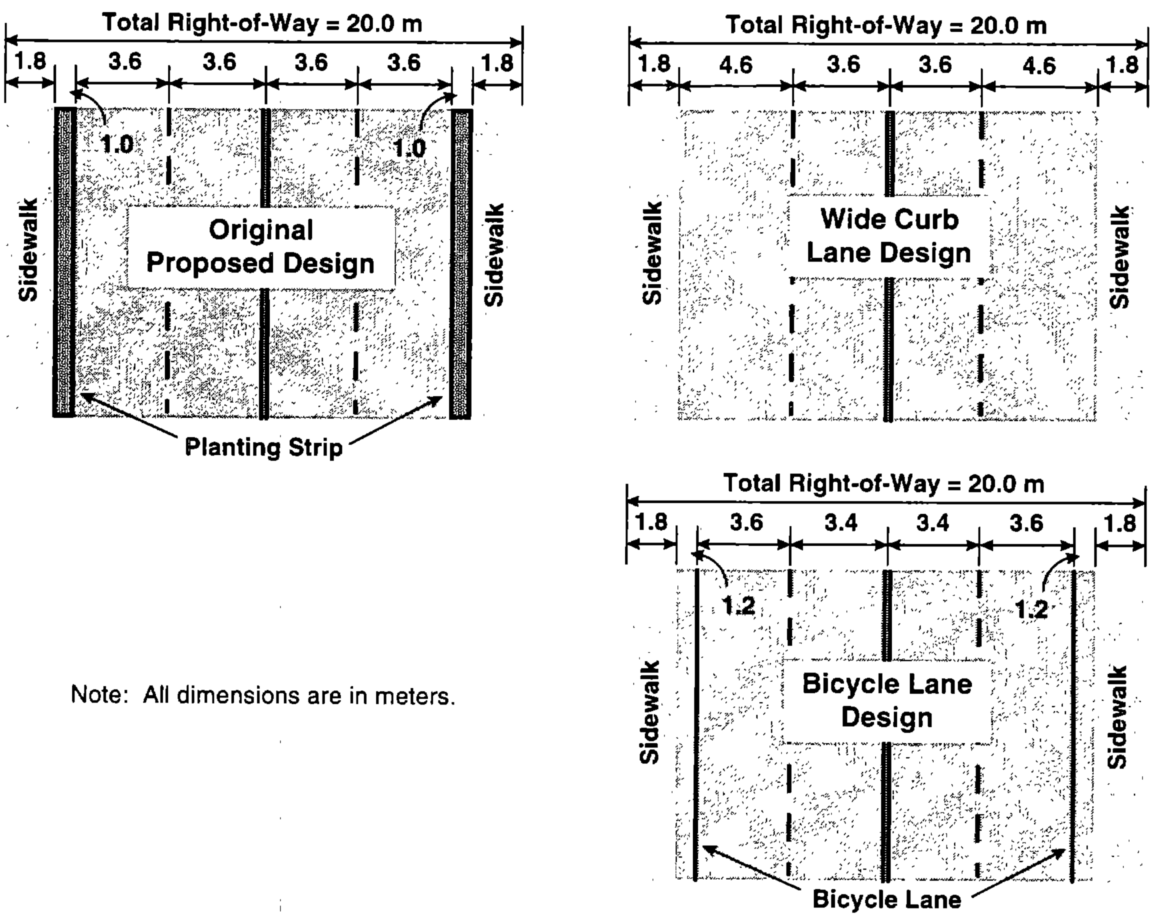


Figure 21. Proposed geometric design options for the reconstruction of a minor arterial.

wide planting strip on each side, and 1.8-m wide sidewalks. No paved shoulders or bicycle lanes were included in the design.

Using the BCI model, the bicycle LOS for the proposed route can be determined as follows. First, the projected AADT of 16,000 vpd must be converted into an hourly volume. The highest hourly volume on this roadway is during the peak hour with 10 percent of the AADT (1,600 vehicles) traveling in both directions during this hour. It is also known that the directional split during the peak hour is 70/30, i.e., 70 percent of the vehicles are traveling in one direction during the peak hour. Thus, 1120 vph (0.7 x 1600) is the directional volume to be used. Since this volume will be distributed across two lanes with 60 percent of the traffic in the curb lane, two final calculations are made to determine the lane volumes as follows:

Curb lane volume (**CLV**)
= 1120 x 0.6 = 672
Other lane volume (**OLV**)
= 1120 x 0.4 = 448

The truck traffic on the roadway was projected to be 2 percent of the AADT. Using the same assumptions for directional splits and lane distributions, the number of trucks per hour in the curb lane becomes 13 (0.02 x 672). From table 16, the adjustment factor (f_t)for this level of truck volume is 0.10.

Using this information and the other data provided, the BCI for the original proposed design was computed as shown in table 18. The calculated BCI was 4.71 which, based on the LOS criteria shown in table 17, results in a bicycle LOS E or a very low level of compatibility for bicycling.

Since this particular roadway presently accommodates a fair volume of commuting bicyclists and is an important link in the bicycle network, it is desired to provide bicycle LOS C or better. Thus, two optional designs are proposed that fit within the 20.0-m-wide right-of-way. The first option is the wide curb lane design in which the planting strip is eliminated and the curb lanes are increased to 4.6 m in width; all other dimensions remain the same. As shown in table 18, this design

Table 18. Bicycle Compatibility Index (BCI) computations and levels of service (LOS) associated with the geometric design options in the example.

Design Option	BCI Model Variables									BCI	LOS
	BL	BLW	CLW	CLV	OLV	SPD	PKG	AREA	AF		
Original Proposal	0	0.0	3.6	672	448	55	0	0	0.1	4.71	E
Wide Curb Lane	0	0.0	4.6	672	448	55	0	0	0.1	4.21	D
Bicycle Lane	1	1.2	3.6	672	448	55	0	0	0.1	3.24	C

Calculations	
Design Option	3.67 - 0.966**BL** - 0.410**BLW** - 0.498**CLW** + 0.002**CLV** + 0.0004**OLV** + 0.022**SPD** + 0.506**PKG** - 0.264**AREA** + **AF**
Original Proposal	3.67 - 0.966(0) - 0.410(0.0) - 0.498(3.6) + 0.002(672) + 0.0004(448) + 0.022(55) + 0.506(0) - 0.264(0) + 0.1
Wide Curb Lane	3.67 - 0.966(0) - 0.410(0.0) - 0.498(4.6) + 0.002(672) + 0.0004(448) + 0.022(55) + 0.506(0) - 0.264(0) + 0.1
Bicycle Lane	3.67 - 0.966(1) - 0.410(1.2) - 0.498(3.6) + 0.002(672) + 0.0004(448) + 0.022(55) + 0.506(0) - 0.264(0) + 0.1

results in a BCI of 4.21, which is equivalent to LOS D and indicates a moderately low level of compatibility for bicycling. While this is an improvement, it does not increase the LOS to the desired level.

The second optional design incorporates a 1.2-m-wide bicycle lane, as shown in figure 22. Again, the planting strip has been eliminated and the original sidewalk width is maintained. The curb lane widths of 3.6 m are also maintained, but the interior lanes are reduced slightly to 3.4 m. The BCI for this option is computed to be 3.24, as shown in table 18. This value equates to LOS C, which indicates a moderately high level of compatibility for bicycling and meets the desired bicycle LOS requirements for the roadway.

This example was provided to illustrate the practical use of the BCI model in evaluating alternative designs to ultimately arrive at a design that could be considered "bicycle friendly." Other examples associated with various aspects of planning and design issues as well as detailed instructions on how to apply the model can be found in the companion report to this document, titled ***The Bicycle Compatibility Index: A Level of Service Concept, Implementation Manual***.

Appendix

A

Literature review

In recent years, several models have been developed in an attempt to associate roadway geometrics and vehicle operations with bicycle safety and/or operations. This appendix provides a discussion of each of these models. The efforts discussed here were progressive in nature with each concurrent effort essentially building on what had been done in the previous study. To better understand how the models were developed and how they relate to one another, the discussion is presented in chronological order.

Bicycle safety index rating

One of the first modeling attempts was the bicycle safety index rating (BSIR) model developed by Davis.[2] The purpose of the model was to relate bicycle safety to the physical and operational features of the roadway. While no specifics were provided regarding how the association of variables within the model was determined, there was an explanation of why specific variables were included. In determining which of the variables to include in the model and the form that the variable would take in the model, three criteria were established:

1) The variable must have direct application to the evaluation of mixed vehicle (i.e., motor vehicles and bicycles) operations.

2) The variable must be quantifiable either through a direct measure or an assigned rating.

3) The variable must be consistent with established data collection practices of local transportation departments.

The developed model is made up of two submodels, one for roadway segments and one for intersections (*see table 19*). The roadway segment submodel is to be used to evaluate uniform segments of roadway between major intersections along a predetermined highway. The intersection submodel is to be used to evaluate the major intersections along this same highway. The overall index for the highway can then be determined by summing all of the individual intersection and roadway segment index values and dividing by the total number of intersections and roadway segments.

This approach produces an average value across the roadway being evaluated and gives equal weighting to roadway segments and intersections.

The roadway segment model included variables for traffic volume, speed limit, outside lane width, pavement conditions, and a variety of geometric conditions. Motor vehicle traffic volume was deemed important as it provides some indication of complexity related to the bicyclist: "the more traffic present on the roadway, the more difficulty a bicyclist will have making left turns, watching for opposing movements, and being noticed by motorists." The average annual daily traffic (AADT) volume was selected as the motor vehicle volume to be included in the model, primarily because it is a variable collected by most transportation departments.

Combined with AADT in the model is the variable number of travel lanes. The traffic volume per travel lane has been used in previous studies and proved to be a good indicator of interaction conditions for bicyclists with passing motorists.[11] In the model, AADT and number of travel lanes are combined as one of the additive factors as follows:

$$\mathbf{AADT/(L*2500)}$$

Thus, any AADT that results in a travel lane volume of more than 2500 vehicles per day (vpd) will create a value greater than 1.0. For example, a two-lane road with an AADT of 7000 would result in a factor of

Table 19. Bicycle safety index rating (BSIR) model.

$$\textbf{BSIR} = \sum_{i=1}^{n} (\text{Segment Safety Index Ratings})/n + \sum_{j=1}^{m} (\text{Intersection Safety Index Ratings})/m$$

Safety Index (Segments) = AADT/(2500L) + S/35 + (14-W)/2 + PF + LF
where:

AADT= average annual daily traffic

L = number of travel lanes

S = speed limit (mi/h)

W= outside lane width in ft (use 14 if $\geq$14 ft)

PF =pavement factor = sum of the following existing conditions:

- 0.50 = cracking
- 0.25 = patching
- 0.25 = weathering
- 0.75 = potholes
- 0.75 = rough edge
- 0.25 = curb and gutter
- 0.50 = rough railroad grade crossing
- 0.75 = drainage grates

LF=location factor = sum of the following existing conditions:

- 0.75 = angle parking
- 0.50 = parallel parking
- 0.25 = right turn lanes
- -0.25 = physical median
- -0.25 = center turn lane
- -0.75 = paved shoulder
- 0.50 = severe grade
- 0.25 = moderate grade
- 0.25 = frequent horizontal curves
- 0.50 = restricted sight distance
- 0.50 = numerous driveways
- 0.50 = industrial land use
- 0.50 = commercial land use

Safety Index (Intersections) = (VC +VR)/10,000 + (2VR)/(VC+VR) + GF + SF
where:

VR = average daily entering volume on route under consideration

VC = average daily entering volume on cross street

SF = signalization factor = sum of the following:

- 0.50 = traffic actuated signal
- 0.75 = substandard clearance interval
- 0.25 = permissive left-turn movement
- 0.50 = right-turn arrow

GF = geometrics factor = sum of the following:

- 0.50 = no left-turn lane
- 0.50 = dual left-turn lane
- 0.75 = right-turn lane
- 0.25 = two through lanes
- 0.50 = three or more through lanes
- 0.25 = substandard curb return radii
- 0.50 = restricted sight distance

1.4. In contrast, a roadway segment with a travel lane volume of less than 2500 vpd will result in a value less than 1.0. The speed limit of the roadway was also included in the model for two reasons. First, it was believed that speed limit provided some reasonable indicator of the design speed of the roadway. Second and more importantly, it was believed to provide some indication of travel speeds of motor vehicles, which directly relates to the speed differential between motorists and bicyclists. While these reasons for using speed limit are sound and the need for some measure of motor vehicle speed is needed in the model, the reasoning does not necessarily hold true for all roadways. In a recent Federal Highway Administration (FHWA) study, 85th percentile speeds on a variety of rural and urban, two-lane and multilane roadways was found to be from 6 to 14 mi/h over the posted speed limit.[12] This is not surprising considering the number of factors that are often considered when a speed limit is set. Another recent study found that while the 85th percentile speed is often used as the principal criterion, engineering judgment and the consideration of other factors often results in the establishment of arbitrary speed limits that do not reflect travel speeds.[13]

The additive factor containing the speed limit variable within the model was written as follows:

$$S/35$$

From previous research, it had been shown that speed differentials between motorists and bicyclists remain fairly constant (between 10 and 15 mi/h) up to motor vehicle speeds of approximately 35 mi/h.[14] In another study, it was shown that more than 50 percent of all bicycle fatalities occurred on roadways with posted speed limits greater than 35 mi/h.[15] Thus, 35 mi/h was selected as the denominator in the speed limit factor within the model. Any roadways with a speed limit of 35 would produce a factor of 1.0; speed limits of 30 and lower would produce factors less than 1.0 and posted speed limits of 40 and higher would produce factors greater than 1.0.

The outside or curb lane width was the next variable included in the model. This variable was included since it determines the travel space available for bicycling within the roadway and the space available for an overtaking motorist who desires to remain in the curb lane during the maneuver. Curb lane widths of 14 ft were cited from two sources as being the desirable width to provide safe bicycling conditions.[16,17] The variable is presented in the model as follows:

$$(14\text{-}W)/2$$

As noted in the variable definitions presented with the model above, any lane width greater than 14 ft will still use a value of 14 ft within the model, i.e., 14 ft is the maximum value that can be used in the model. Based on this definition, any lane width greater than or equal to 14 ft will produce a factor of zero. One problem with this restriction is that no benefit is gained from curb lane widths of 15 ft or greater. If larger values were used, a negative value would be produced, which would reduce the index value. Lane widths less than 14 ft will produce positive values that will add to the index. For example, a lane width of 12 ft would produce a positive factor of 1.0.

Pavement condition was the next variable included in the model. This variable was included because defects or irregularities in the paved surface can affect the comfort and safety of bicyclists. As noted in the variable definitions presented with the model above, eight different conditions are provided to define detrimental pavement surfaces. Each of these conditions has a value assigned to it. An explanation of how these values were derived was not provided. An examination of the values, however, does seem to indicate that some degree of relative importance was assigned within the factor itself. For example, potholes, rough edges, and drainage grates are perhaps the most dangerous to bicyclists and, thus, were assigned the largest value (0.75). Patching, weathering, and curb and gutter on the other hand, are not nearly as problematic for bicyclists and were assigned a value of 0.25. The other conditions (rough railroad crossings and cracking) were considered to fall in between the two extremes and were assigned a value of 0.50.

The last factor in the model is the location factor, which incorporates a variety of measures related to both geometrics and operations along a roadway segment. Those for bicyclists were assigned a positive value while those conditions which potentially improve bicycle safety were assigned a negative value. For example, parking along the roadside, grades, restricted sight distances, and driveways all received positive values. Paved shoulders and physical medians received negative values. As with the pavement factor, no detailed explanation was given regarding how these assigned values were derived, but there does seem to be relative importance among the operational and geometric conditions present within the factor. The condition perceived to be the most beneficial was the presence of a paved shoulder, with a value of -0.75, while the condition perceived to create the greatest safety hazard was angle parking, with a value of 0.75.

As with the roadway segment model, traffic volume was deemed important at the intersection because it provides some indication of the level of complexity. The first factor is intended to simply provide a number relative to the total entering volume at a given intersection. If this volume is greater than 10,000 vpd, the factor will be greater than 1.0, indicating a more difficult intersection for the bicyclist. The second volume-related factor is intended to provide some indication of the level of difficulty that would be experienced by a bicyclist on a low-volume street crossing a high-volume street or vice versa. As an example, assume a bicyclist on a street with an entering volume of 20,000 vpd is crossing a street with an entering volume of 5,000 vpd. The factor for these conditions becomes 1.6. If the bicyclist is on the low-volume roadway and is crossing the high-volume street, the factor becomes 0.4. Intuitively, this factor appears to provide an opposite result of what is expected; in most cases, exclusive of signalization and geometrics, one would hypothesize that it would be more difficult for the bicyclist to cross the high-volume roadway than the low-volume roadway. Again, there is no explanation regarding the development of these factors. Thus, a full understanding of what the author intended the factor to represent is difficult.

The geometrics variable is the next factor included in the model. This variable was intended to quantify the traffic maneuver complexity of the intersection. The number of lanes and type of lane are the predominant variables included in this factor, with a right-turn lane being given the highest value of 0.75. This probably reflects the fact that the provision of such a lane for motor vehicles produces a weaving situation for motorists turning right and bicyclists proceeding through the intersection. Restricted sight distance and substandard curb radii are also geometric variables that should be considered as part of the factor.

The last factor in the intersection model is the signalization factor. These factors are intended to indicate how signal operations at a specific intersection may impact upon the safety of the bicyclists. If a signal is actuated, it is considered to have a negative impact on bicycling safety resulting from the fact that bicyclists often cannot be detected by the detection loops.[18] This fact, in turn, can result in the bicyclist crossing against the light and putting him or herself in a dangerous situation. If the clearance interval is sub-standard, i.e., not long enough for bicyclists, a value of 0.75 is used. A value of less than 4.0 s is considered substandard in the model. Finally, if permissive left turns are allowed or if right-turn arrows are present, conditions are present that may require motorists to yield to bicyclists, which may create a hazardous situation.

A case study using the developed models was conducted in Chattanooga, Tennessee. A total of seven roadways consisting of 21 uniform segments and 29 major intersections were included in the study. The appropriate indexes were computed for each segment and intersection and then combined to form the overall index rating (BSIR) for each roadway. The ratings produced for the seven roadways ranged from 4.46 to 6.54. Relative comparisons were made between each individual rating and the other six ratings. On the basis of the author's knowledge of the roadways selected and the ratings produced from the models, a classification scheme was developed to define bicycle operation based on the BSIR values (*see table 20*). Of the seven roadways included in the case study, two were classified as "good," three were classified as "fair," and two were classified as "poor."

As noted by the author, these indexes are not definitive values, but instead assign general designations to roadways that can be used in determining bicycle routes, preparing bicycle maps, or prioritizing improvements for bicycling. While this study provides a good starting point for examining specific variables that may be important to bicycle operations, it was not able to conclusively define how important specific variables were to either bicycle safety or operations. First, there was no bicycle accident analysis conducted on any of the segments included in the case study. Thus, the term bicycle "safety" index rating is misleading. While there is no argument that many of the factors included may impact upon the safety of bicyclists operating concurrently with motor vehicles, the validation of how these factors actually impact upon safety was not performed. Second, the classification scheme developed was based entirely on the relative differences in the indexes produced and the author's knowledge of the routes. This method of developing a classification scheme is problematic from the standpoint that: 1) it relies on the subjective judgment of the author to establish the scale of what is considered excellent, good, fair, or poor; and 2) the classification scheme may not be transferable to other cities or even other locations within the city since the relative differences between the sites used played a large part in establishing the scheme.

Finally, there is the problem of combining the results from the two submodels into a single rating. Since the final result was simply an average of all intersection and segment values produced for the roadway, it was assumed that roadway segments are equivalent to intersections in terms of safety or

Table 20. Rating classifications for the bicycle safety index rating (BSIR).[3]

Index Range	Classification	Description
0 to 4	Excellent	Denotes a roadway extremely favorable for safe bicycle operation.
4 to 5	Good	Refers to roadway conditions still conducive to safe bicycle operation, but not quite as unrestricted as in the excellent case.
5 to 6	Fair	Pertains to roadway conditions of marginal desirability for safe bicycle operation.
6 or above	Poor	Indicates roadway conditions of questionable desirability for bicycle operation.

operational difficulty for the bicyclist. Recent work has shown that 50.4 percent of all bicycle accidents occur at intersections or are intersection related.[19] An additional 21.4 percent of the bicycle accidents occur at other types of junctions, such as driveways. These results indicate a need to perhaps weight intersections significantly more when combining results. It is also possible that the two scenarios, intersections and segments, cannot be combined; they are simply too different in terms of the maneuvers required, the type and number of conflicts encountered, and the overall geometric and operational conditions.

Table 21. Modified pavement and location factors used in the Florida roadway condition index.[3]

Pavement factors	
0.50	= cracking
0.25	= patching
0.25	= weathering
0.25-0.50	= potholes, depending on severity
0.25-0.50	= rough road edge, depending on severity
0.25	= railroad crossing
0.50	= rough or angled railroad grade crossing
0.50	= drainage grates
Location factors	
0.75	= angle parking
0.25	= parallel parking
0.25	= right-turn lane (full length)
-0.50	= raised median (solid)
-0.35	= raised median (left-turn bays)
-0.20	= center turn lane
-0.75	= paved shoulder or bike lane
0.50	= severe grade
0.20	= moderate grade
0.35	= frequent horizontal curves
0.50	= restricted sight distance
0.25	= numerous driveways
0.25	= industrial land use
0.25	= commercial land use

Florida roadway condition index

In 1991, the bicycle programs in Broward County and Hollywood, Florida, were interested in developing objective ratings for their roadway system as it related to bicycle operations. The BSIR, discussed above, was used as the evaluation tool with some minor changes. First, only the roadway segment portion of the BSIR was used in the evaluation. Intersections were not rated as part of this effort, and each roadway segment between two intersections maintained a single rating (i.e., ratings for two or more roadway segments were not combined into a single weighted value). Second, the values used for some of the pavement and location factors were modified in an attempt to reduce the weight of these factors within the model. An examination of the results from the Chattanooga case study revealed that, on average, the pavement and location factors accounted for 30 percent of the BSIR. The revised values are shown in table 21.[3]

The next change was for the Hollywood model only; the model was modified to place greater weight on those segments where narrow lanes and high motor vehicle speeds occurred simultaneously. This was done by multiplying the speed limit term by the lane width term. The speed limit used in the denominator was also reduced from 35 mi/h to 30 mi/h, again increasing the weighting of the speed factors. Finally, the traffic volume in the denominator was increased to from 2500 to 3100, which, in turn, reduced the weight of the traffic volume factor. The resulting model was termed the roadway condition index (RCI), reflecting the fact that it was an indicator of conditions rather than a predictor of crashes, and took the form shown in table 22.

Since Hollywood is located within Broward County, a number of roadways were rated using both models. Percent differences in the actual values produced

Table 22. Roadway condition index (RCI) model.[3]

RCI = AADT/(3100L) + S/30 + {(S/30)[(14-W)/2]} + PF + LF	
where:	
AADT = average annual daily traffic	W = outside lane width in ft (use 14 if $\geq$ 14 ft)
L = number of travel lanes	PF = pavement factor
S = speed limit (mi/h)	LF = location factor

ranged from 0 to 19 percent, with the modified BSI model, used in Broward County, normally producing higher values than the RCI model, used in Hollywood. As noted by the author, the RCI model was more sensitive to changes in lane width and speed and less sensitive to changes in AADT. This effect should have been expected considering the modifications made to the model.

One goal that was achieved in the results from both models was the reduction in the contribution of the pavement and location factors to the overall rating. In Broward County, the modified BSIR, which included only changes in the values assigned to the various conditions, resulted in an 11 percent contribution to the index rating by both factors. In Hollywood, the two factors contributed only 9 percent to the RCI rating.

An attempt to use the RCI model to predict crashes was also undertaken. Bicycle crashes over a 20-month period in Hollywood were linked to specific roadway segments and ranked from one to five, depending on severity (with five being fatal). Sums were computed for each segment and divided by the length of the segment, resulting in an accident frequency per mile weighted by severity. The analysis conducted showed the RCI model to explain only 18 percent of the variation in the crash scores between roadway segments. The first reason for this poor result may simply be the means by which the crash measure was expressed. A much better way to describe the crash would be in terms of "per bicycle miles ridden" or "per number of motor vehicle encounters per mile" or some other exposure measure. The lack of bicycle exposure data on the roadway segments was the principal reason noted by the authors in explaining the poor results of the analysis.

In 1993, the RCI model was modified and applied in Dade County, Florida (*see table 23*). The only variable not previously defined is HV, which is the percentage of heavy vehicles in the traffic stream and is expressed as a decimal. The values and descriptive terms for the pavement and location variables were simplified. The pavement surface was rated as either excellent, good, fair, or poor and assigned

Table 23. Modified roadway condition index (MRCI) model.[3]

MRCI = [AADT/(3100L)](S/30)(14/W)[1.8(1 + HV)][1 + (0.03PF) + (0.02LF)]	
where:	
AADT = average annual daily traffic	PF = pavement factor
L = number of travel lanes	LF = location factor
S = speed limit (mi/h)	HV = percentage of heavy vehicles
W = curb lane width in ft (use 14 if $\geq$ 14 ft)	

values of 0, 1, 2, and 3, respectively. The location factor was defined solely in terms of cross-traffic generation, which was either little, moderate, or heavy with values of 1, 2, and 3, respectively.

The change in the arrangement of terms in the model produced similar values to the previous version, but changed the weighting of terms within the model. The pavement and location factors in the modified version were less of a factor in the overall index. Additional roadway width beyond 14 ft was now included in the pavement width term as a positive factor. Finally, the terms for lane width, speed, and traffic volume were multiplied in an attempt to increase the interaction between the terms, which is more representative of the real world. This multiplicative format also allowed for the use of an exponential scalar. The value of 1.8 was used in the model to accentuate changes in the index at the top and bottom of the ranges, which improved the fit to low-volume roads while not significantly affecting higher volume locations. Even with the changes in assigned values and modifications to the model equations, there was still the need to interpret the index ratings produced by the various models and develop a classification scheme to identify the various levels at which roads were and were not compatible for bicycling operations. As with the BSIR, this development of such a scheme seemed to be subjective, based on the individual or collective knowledge of bicycle researchers, coordinators, and possibly others, and the relative results produced by the models. For the RCI model, the classification scheme was simply shifted down by one number from what had been developed for the BSIR model (*see table 24*). The descriptions for the classifications remained the same as previously shown in table 20. For the MRCI model used in Dade County, the classifications as well as the descriptions were modified. A roadway segment with a value between 0 and 4.0 was determined to provide an adequate level of service for less experienced bicyclists or children. A rating of 5.0 or lower was considered to provide an adequate level of service for more experienced bicyclists.

Table 24. Comparison of the bicycle safety index rating (BSIR) model and the roadway condition index (RCI) model.[2,3]

BSIR Index Range	RCI Index Range	Classification
0 to 4	0 to 3	Excellent
4 to 5	3 to 4	Good
5 to 6	4 to 5	Fair
6 or above	5 or above	Poor

Bicycle interaction hazard score

The interaction hazard score (IHS) was the next model developed and was based heavily on the prior models.[4] The model was developed in an attempt to overcome two problems noted with the previous models: 1) the substantial subjectivity used in estimating the values of some of the variables, and 2) the lack of consideration of the exposure variables. It is not clear what is meant by exposure. This could be the level of bicycling on a particular roadway, expressed as a volume or number of bicycle miles ridden, or it could be the number of hazards to which the bicyclist is exposed along a route.

In deciding which variables to include in the model, all on-road bicycle interactions were divided into two distinct groups. The first group was termed the "longitudinal roadway environment" and included variables that affect the bicyclist's perception of hazard. Variables in this group included volume, speed, and size of the motor vehicles using the shared roadway, proximity of the bicyclist to these vehicles, and pavement condition of the travel lane for the bicyclist. The second group was termed the "transverse roadway environment" and included variables that represent uncontrolled vehicular movements that may present a hazard to the bicyclist on the shared roadway. Variables in this group included frequency of driveways and on-street parking presence and turnover.

Combining some of the terms from the prior models with some additional terms to account for the variables just mentioned, the IHS model took the form shown in table 25.

Once the model was developed, baseline conditions for a two-lane minor arterial were used for calibration. Coefficients for a_1, a_2, and a_3 were established to be 0.01, 0.01, and 0.024, respectively. These coefficients resulted in the speed factor producing 79 percent of the model's value. The pavement condition factor and the land use/curb cut factor produced 13 percent and 8 percent of the equation's value, respectively. A sensitivity analysis was also conducted to show how changes in a specific variable affected the overall value of the model. This analysis was performed for each variable and compared with the baseline conditions established for the two-lane minor arterial. The author concludes that the values established for the coefficients and the results of the sensitivity analysis are valid on the basis of interviews with bicyclists and group meetings. However, no results from any of these meetings or interviews were provided to assess the actual validity. Thus, it appears that the goal of eliminating

Table 25. Interaction hazard score (IHS) model.[4]

$$\mathbf{IHS = \{(ADT/L)(14/W)^2\, [a_1(S/30)(1 + \%HV)^2 + a_2PF] + a_3LU(CCF)\}/10}$$

where:

ADT = average daily traffic.

L = total number of through lanes.

W = usable width of the outside through lane (ft), including the width of any bike lanes; measured from the pavement edge or gutter pan to the center of the lane line or center line.

HV = percentage of heavy vehicles, expressed as a decimal.

a_1 - a_3 = calibration coefficients initially equal to unity.

LU = land use (intensity) adjoining the road segment (commercial = 15 (when 30 percent or more of the land is developed as something other than residential or agricultural); noncommercial = 1).

CCF = curb cut or on-street parking frequency (a measure of uncontrolled access, i.e., turbulence per unit distance).

S = speed limit (mi/h).

PF = pavement factor (the reciprocal of the FHWA Highway Performance Monitoring System PAVECON factor, where:

- 5.0 = very good - only new or nearly new pavements are likely to be smooth enough and free of cracks and patches to qualify for this category.
- 4.0 = good - pavement, although not as smooth as those described above, gives a first-class ride and exhibits signs of surface deterioration.
- 3.0 = fair - riding qualities are noticeably inferior to those above, may be barely tolerable for high-speed traffic. Defects may include rutting, map cracking, and extensive patching.
- 2.0 = poor - pavements have deteriorated to such an extent that they affect the speed of free-flow traffic; flexible pavement has distress over 50 percent or more of the surface; rigid pavement distress includes joint spalling, patching, etc.
- 1.0 - very poor - pavements that are in an extremely deteriorated condition; distress occurs over 75 percent or more of the surface.

subjectivity from the modeling process was not totally achieved within the IHS. It is also not clear whether the goal of increasing consideration for exposure was met. As previously noted, the author did not explicitly define exposure. If the goal was to improve the use of bicycle exposure measures within the model, such as bicycle volumes, the model was unsuccessful. However, if exposure was defined as potential hazards to the bicyclist, then the model did tend to include measures that were directly applicable and more objective when compared with previous models.

Conclusions

All of the models discussed here were good attempts at trying to define bicycle operations (and sometimes safety) under varying roadway conditions. Altogether, there were five different models described, with each one building on what had been done in the previous efforts. As each successive model was developed, there seemed to be a desire to remove the subjectivity from the process. Unfortunately, this was never totally achieved. In all cases, there was the need to interpret the various indexes produced and decide what the breakpoints were that separated a roadway with good bicycling operations from one that was excellent or fair or poor. The means of accomplishing this in each case was to produce the index ratings, examine them in relation to each other and, based primarily on the "street" knowledge of the author with regard to which roadways he thought were good and bad for bicycling, establish the subjective breakpoints in the classification scheme.

It should be noted that the authors did recognize the need to further validate their work. The primary suggestion from two of the authors was to incorporate the opinions of bicyclists regarding perceived hazards and riding comfort.[3,4] Several means of accomplishing this goal were suggested, including:

1) having bicyclists actually ride on a number of different roadways;

2) having bicyclists complete questionnaires or participate in roadside interviews designed to quantify different types of hazards;

3) having the bicyclists view videotapes of different roadway segments and evaluate them in much the same way as they would if they were riding the segment.; or

4) observing which routes bicyclist choose in going from an origin to a destination and how long they are willing to ride on each specific roadway segment.

In this research effort, it was the video technique that was adapted from prior work by Sorton and Walsh and validated as discussed in chapter 2. Another research effort recently conducted adopted the approach of having bicyclists ride in the roadway on a limited number of segments.[20] As in this effort, the subjects in that study also provided "comfort" ratings on a six-point scale for each of the segments ridden, exclusive of intersections.

The bicycle level of service (BLOS) model developed from the bicyclists' surveys is shown in table 26. The model had an R^2-value of 0.73 and incorporated a number of variables related to geometrics, operations, and trip generation characteristics. While there are some differences between this model and the BCI model with respect to significant terms, the primary terms of width, presence or absence of a bicycle lane, traffic volume, and motor vehicle speed, are present in both. However, the BLOS model contains a number of additional variables that would not be readily available to most practitioners (e.g., pavement condition rating and detailed land-use information); obtaining such data could be cost-prohibitive for some agencies. The BCI model developed in the current research study attempted to be sensitive to this issue, and thus minimizes the amount of additional data that may be required.

One of the major differences between the BCI model and the BLOS model is the inclusion of the term pavement condition in the BLOS model. The developers of the model insist that this variable is critical to determining the quality of service for bicyclists. The authors of this report do not disagree with that statement, but take the position that bicycle routes should not be established on the basis of that criterion. Instead, the geometric and operations variables identified as significant in the BCI model should be used for establishing bicycle level of service and subsequently appropriate routes. The surface quality of those routes on the bicycle network should then be maintained to minimize hazards and provide a quality ride for bicyclists.

Table 26. Bicycle level of service (BLOS) model.[20]

$$BLOS = a_1 \ln(Vol_{15}/L) + a_2 \ln(SPD_p(1+\%HV)) + a_3 \ln(COM15NCA) + a_4(PC_5)^{-2} + a_5(W_e)^2 + C$$

where:

BLOS	=	perceived hazard of the shared roadway environment
Vol_{15}	=	volume of directional traffic in 15-min time period
L	=	total number of *through* lanes
SPD_p	=	posted speed limit (a surrogate for average runnning speed)
HV	=	percentage of heavy vehicles (as defined in the 1994 *Highway Capacity Manual*)
COM15	=	trip generation intensity of the land use adjoining the road segment (stratified to a commercial trip generation of "15", multiplied by the percentage of the segment with adjoining commercial land development.
NCA	=	effective frequency per mile of non-controlled vehicular access (e.g., driveways and/or on-street parking spaces)
PC_5	=	FHWA's five-point pavement surface condition rating
W_e	=	average effective width of outside through lane:

$$= W_t + (PC_t/PC_5W_1) - \Sigma W_r$$

where:

W_t = total width of outside lane (and shoulder) pavement

W_l = width of paving between the outside lane stripe and the edge of pavement

W_r = width (and frequency) of encroachments in the outside lane,

$$= W_p * \% \text{ of segment with on-street parking} + (W_g N/66L_s)$$

where:

W_p = width of pavement occupied by on-street parking activity

W_g = averaged width of stormwater grates

N = number of grates on the segment

L_s = length of the segment

C = constant

Appendix

B

Pilot study data analysis

As previously noted in chapter 2, the primary objective of the pilot study in this research effort was to validate the video methodology, i.e., determine how well the participants' comfort ratings assigned when watching locations on a videotape ***matched*** the participants' ratings when viewing the same locations in the field. In chapter 2, a summary of the results of the data analysis was provided. A more extensive discussion of the statistical analysis is provided in this appendix.

Since each of the 24 participants (subjects) viewed the 13 sites both from the videotape and in the field, the most stable and reliable analyses are based on the 312 (24 × 13) combined pairs (video vs. field) of observations. Thus, the analysis focuses on the combined sample of comfort ratings, including the overall rating as well as those related to curb lane width, volume, and speed of traffic.

However, analyses were also carried out by subject to examine: 1) possible biases (e.g., generally rating the video slightly higher than the field observation); 2) consistency (i.e., providing essentially the same ratings for each pair of matched video clips); and 3) order of presentation differences (i.e., differences between the participants who saw the video first followed by the field observations vs. those who saw the field sites first followed by the video). Finally, the ratings by site were investigated to see if the participants' ratings between the field and video were more consistent for some sites compared with others and, if so, to determine the characteristics of those sites where the participants were less consistent in their ratings.

The basic data for this study consisted of a sample of matched pair comfort ratings (field vs. video) for each of 24 participants. As noted in chapter 2, there were two video clips of the same site in the survey, each with a different traffic volume. One of the clips contained the "uniform" volume condition while the other clip contained the "representative" volume condition. Since the objective of this analysis was to directly compare the ratings between field and video observations, the video clip that most closely matched the field volume observed by each participant was used as the matching clip. As such the data can best be represented by contingency tables with rows (i) representing the field ratings (i = 1, 2, ..., 6) and columns (j) representing the video ratings (j = 1, 2, ..., 6). Further, the ratings can be defined as follows:

OFR(i)=	overall field rating
OVR(j)=	overall video rating
WFR(i)=	width field rating
WVR(j)=	width video rating
VFR(i)=	volume field rating
VVR(j)=	volume video rating
SFR(i)=	speed field rating
SVR(j)=	speed video rating

If there were perfect agreement between the field and video ratings (e.g., $OFR(i) \equiv OVR(j)$), then all pairs of overall ratings would fall along the main diagonal of the contingency table (or matrix). If the video ratings were consistently somewhat higher than the field ratings (e.g., $OFR(i) \leq OVR(j)$) or vice versa, the pairs of overall ratings would consistently fall above or below the main diagonal of the contingency table, respectively. The following analyses examined these possible relationships.

The results of the field vs. video overall ratings for the 312 subject-by-location pairs are shown in table 27. Note first that the column marginal distribution for the video

Table 27. Field (OFR) vs. video (OVR) overall ratings for the combined subject by location sample.

		OVR(j)						Total (%)	
		1	2	3	4	5	6		
OFR(i)	1	10	6	4	1	0	0	21	(6.7)
	2	6	30	28	4	0	0	68	(21.8)
	3	1	24	36	19	2	0	82	(26.3)
	4	0	8	31	22	14	2	77	(24.7)
	5	0	5	11	17	15	3	51	(16.3)
	6	0	0	4	4	3	2	13	(4.2)
Total (%)		17 (5.5)	73 (23.4)	114 (36.5)	67 (21.5)	34 (10.9)	7 (2.2)	312	

(namely, 5.5%, 23.4%, ..., 2.2%) is similar to the row marginal distribution for the field ratings (namely, 6.7%, 21.8%, ..., 4.2%). This suggests that, overall, the video ratings are reasonably reliable predictors of the field ratings. Table 28 indicates the degree of agreement between the field and video overall ratings. In 36.9 percent of the sample, there is perfect agreement whereas in 85.3 percent of the cases, the ratings differ by no more than one level. And in 96.8 percent of the pairs, the difference is two levels or less. Also note that when OFR is not equal to OVR, the field rating is more often higher (36.6% = 26.0 + 7.7 + 2.9) than the video rating (26.5% = 22.4 + 3.8 + 0.3). Such is not the case, however, with the speed or volume ratings discussed later.

Cohen's κ (kappa) statistic is a nonparametric measure of the degree of agreement among pairs of ratings that is appropriate to further quantify these relationships.[21] The results of calculating Cohen's κ and the natural extension to near diagonal cells are also shown in table 28. For the perfect agreement condition (main diagonal), the Cohen's κ is 0.19, which indicates a "fair" level of agreement between the field and video ratings. The extended Cohen's κ for the video rating being within one level of the field rating is 0.62, which suggests "substantial" agreement.

The corresponding results for ratings based on curb lane width (W), speed (S), and traffic volume (V) are presented in tables 29 through 34, respectively. For the most part, the results are quite similar to those for the overall ratings. The row and column marginal distributions are quite similar for each of the three variables, indicating that the video ratings for each variable are fairly reliable predictors of the field ratings.

For the curb lane width variable, the field rating (WFR) is within one level of the video rating (WVR) for 39.4 percent of the pairs and the corresponding Cohen's κ is 0.25, indicating a fair level of agreement. In 81.1 percent of the cases, the ratings differ by no more than one level, and the corresponding extended Cohen's κ is 0.60, indicating a substantial level of agreement. Similar to the overall ratings, the field rating for curb lane width was more often higher (40.4% = 27.6 + 9.0 + 3.8) than the video rating (19.8% = 14.1 + 5.1 + 0.6) when the ratings were not equal.

The results for the traffic volume variable indicate that 30.8 percent of the sample pairs match, with a corresponding

Table 28. Level of agreement in the field (OFR) vs. video (OVR) overall ratings.

Condition	Percent of Sample	Cumulative Percent	Cohen's κ	
OFR = OVR (main diagonal)	36.9	36.9	0.19	
OFR + 1 = OVR (above and within 1 of main diagonal)	22.4		0.38[A]	0.62[C]
OFR - 1 = OVR (below and within 1 of main diagonal)	26.0	85.3	0.29[B]	
OFR + 2 = OVR OFR - 2 = OVR	3.8 7.7	96.8		
ORF + 3 = ORV ORF - 3 = ORV	0.3 2.9	100.0		

[A] Cohen's κ extended to include cells within one rating level above the main diagonal.
[B] Cohen's κ extended to include cells within one rating level below the main diagonal.
[C] Ratings within one level of each other (i.e., within one above or below the main diagonal).

Cohen's κ of 0.11, indicating a fair level of agreement. In 82.4 percent of the cases, the ratings differ by no more than one level, and the corresponding Cohen's κ is 0.55, indicating a substantial level of agreement. In contrast to the overall and curb lane width results, the video rating for volume was more often higher (37.5% = 28.5 + 7.7 + 1.3) than the field rating (31.4% = 23.1 + 7.7 + 1.3) when the ratings were not equal.

The results for the speed variable produced the highest match rate (43.6 percent) between the sample pairs of the four variables examined. The corresponding Cohen's κ was 0.23, again indicating a fair level of agreement. In 87.2 percent of the cases, the ratings differ by no more than one level, and the corresponding Cohen's κ was 0.59, again indicating a substantial level of agreement. Similar to the results for the volume variable, the video rating for speed was more often higher (33.0% = 25.0 + 7.4 + 0.6) than the field rating (23.4% = 18.6 + 4.2 + 0.6) when the ratings were not equal.

Table 29. Field (WFR) vs. video (WVR) width ratings for the combined subject by location sample.

		WVR(j)						Total (%)	
		1	2	3	4	5	6		
WFR(i)	1	17	11	6	2	0	0	36	(11.5)
	2	10	35	14	6	0	0	65	(20.8)
	3	1	25	18	6	3	0	53	(17.0)
	4	2	13	31	28	8	1	83	(26.6)
	5	1	8	9	13	20	5	56	(18.0)
	6	0	0	2	5	7	5	19	(6.1)
Total (%)		31 (9.9)	92 (29.5)	80 (25.6)	60 (19.2)	38 (12.2)	11 (3.5)	312	

Table 30. Level of agreement in the field (WFR) vs. video (WVR) width ratings.

Condition	Percent of Sample	Cumulative Percent	Cohen's κ	
WFR = WVR (main diagonal)	39.4	39.4	0.25	
WFR + 1 = WVR (above and within 1 of main diagonal)	14.1		0.49[A]	0.60[C]
WFR - 1 = WVR (below and within 1 of main diagonal)	27.6	81.1	0.26[B]	
WFR + 2 = WVR WFR - 2 = WVR	5.1 9.0	95.2		
WFR + 3 = WVR WFR - 3 = WVR	0.6 3.8	99.6		

[A] Cohen's κ extended to include cells within one rating level above the main diagonal.
[B] Cohen's κ extended to include cells within one rating level below the main diagonal.
[C] Ratings within one level of each other (i.e., within one above or below the main diagonal).

Chi-square tests of marginal homogeneity (i.e., similar marginal distributions for field ratings and video ratings) showed the distributions to be most similar for the speed and volume ratings ($p > 0.25$ and $p > 0.10$, respectively) and reasonably similar for the overall ratings ($p = 0.06$). However, due to the large differences between field and video ratings at levels 3 and 4 for the curb lane width ratings, the video and field ratings distributions for this variable did differ significantly ($p < 0.01$). For the most part, the various video ratings distributions did reflect the field ratings distributions, confirming earlier results that examined the levels of agreement between the ratings.

The analysis just discussed examined the ratings of all participants across all sites. The results are considerably more variable with respect to participants (N=24) across sites and with respect to sites (N=13) across participants. Thus, a paired comparison t-test was undertaken to explore these specific aspects. The primary interest here is

Table 31. Field (VFR) vs. video (VVR) volume ratings for the combined subject by location sample.

		VVR(j)						Total (%)
		1	2	3	4	5	6	
VFR(i)	1	17	22	5	2	0	0	46 (14.7)
	2	16	22	30	9	2	0	79 (25.3)
	3	2	20	39	23	6	0	90 (28.9)
	4	0	12	26	12	8	4	62 (19.9)
	5	1	0	10	9	5	6	31 (9.9)
	6	0	0	2	0	1	1	4 (1.3)
Total (%)		36 (11.5)	76 (24.4)	112 (35.9)	55 (17.6)	22 (7.1)	11 (3.5)	312

Table 32. Level of agreement in field (VFR) vs. video (VVR) volume ratings.

Condition	Percent of Sample	Cumulative Percent	Cohen's κ	
VFR = VVR (main diagonal)	30.8	30.8	0.11	
VFR + 1 = VVR (above and within 1 of main diagonal)	28.5		0.20[A]	0.55[C]
VFR - 1 = VVR (below and within 1 of main diagonal)	23.1	82.4	0.31[B]	
VFR + 2 = VVR VFR - 2 = VVR	7.7 7.7	97.8		
VFR + 3 = VVR VFR - 3 = VVR	1.3 0.6	99.7		

[A] Cohen's κ extended to include cells within one rating level above the main diagonal.
[B] Cohen's κ extended to include cells within one rating level below the main diagonal.
[C] Ratings within one level of each other (i.e., within one above or below main diagonal).

not only in the significance of the test, but also in the sign of the test statistic. A positive sign (+) suggests that the video rating was generally lower than the field rating while a negative sign (-) suggests that the field rating was generally lower than the video rating. A non-significant test statistic suggests that, within pairs, the field and video ratings do not differ. With respect to the overall ratings, 21 of 24 subjects had non-significant (at α = 0.05) t-statistics across sites. With 16 out of 23 being positive (one case where t=0), the tests suggest that the subjects tended to give slightly higher ratings when viewing the sites in the field when compared with viewing the same sites on the video.

With respect to the overall ratings, 21 of 24 subjects had non-significant (at α = 0.05) t-statistics across sites. With 16 out of 23 being positive (one case where t = 0), the tests suggest that the subjects tended to give slightly higher ratings when viewing the sites in the field when compared with viewing the same sites on the video.

Table 33. Field (SFR) vs. video (SVR) speed ratings for the combined subject by location sample.

		SVR(j)						Total (%)	
		1	2	3	4	5	6		
SFR(i)	1	11	3	1	1	0	0	16	(5.1)
	2	2	32	24	10	1	0	69	(22.1)
	3	2	17	54	34	11	0	118	(37.8)
	4	0	3	29	32	16	1	81	(26.0)
	5	0	2	7	8	6	1	24	(7.7)
	6	0	0	0	1	2	1	4	(1.3)
Total (%)		15 (4.8)	57 (18.3)	115 (36.9)	86 (27.6)	36 (11.5)	3 (1.0)	312	

Table 34. Level of agreement in field (SFR) vs. video (SVR) speed ratings.

<table>
<tr><th>Condition</th><th>Percent of Sample</th><th>Cumulative Percent</th><th colspan="2">Cohen's κ</th></tr>
<tr><td>SFR = SVR (main diagonal)</td><td>43.6</td><td>43.6</td><td colspan="2">0.23</td></tr>
<tr><td>SFR + 1 = SVR (above and within 1 of main diagonal)</td><td>25.0</td><td></td><td>0.26[A]</td><td rowspan="2">0.59[C]</td></tr>
<tr><td>SFR - 1 = SVR (below and within 1 of main diagonal)</td><td>18.6</td><td>87.2</td><td>0.42[B]</td></tr>
<tr><td>SFR + 2 = SVR
SFR - 2 = SVR</td><td>7.4
4.2</td><td>98.8</td><td colspan="2" rowspan="2"></td></tr>
<tr><td>SFR + 3 = SVR
SFR - 3 = SVR</td><td>0.6
0.6</td><td>100.0</td></tr>
</table>

[A] Cohen's κ extended to include cells within one rating level above the main diagonal.
[B] Cohen's κ extended to include cells within one rating level above the main diagonal.
[C] Ratings within one level of each other (i.e., within one above or below the main diagonal).

As previously noted in chapter 2, half of the 24 subjects viewed the video first and then went to the site whereas the other half visited the site first. There were no clear differences in these two groups with respect to whether they rated the field scene higher or lower than the video clip as judged by the significance or sign (+ or -) of the corresponding t-statistics.

Similar results were seen when comparing the field and video ratings for curb lane width, volume, and speed by subject. The main difference was that while subjects tended to rate the field view slightly higher than the video clip for both the overall and width variables, the opposite was true for the volume and speed variables. This result is similar to what was found in the analysis of the 312 combined pairs.

One of the objectives of the pilot study was to determine how consistent participants were in rating the same conditions. To achieve this objective, there were 26 identical pairs of video clips included in the video survey. The video ratings for the 26 matched clips were compared. Here the rows of the contingency table represented the overall rating of each of the 24 subjects for the first time the clip was shown while the columns of the table represented the ratings of the subjects for the second time the same scene was displayed. For the overall ratings, 20 of the 26 had non-significant t-tests suggesting consistent ratings. And 20 of 25 had a positive sign (one case where t = 0), indicating that the rating was slightly higher for the second clip. The results were most similar for the width, volume, and speed ratings.

The final analysis issue dealt with strength of agreement between the field and video ratings on a site-by-site basis in an attempt to determine if there were characteristics of certain sites that led to inconsistencies in the video vs. field ratings. Using paired comparisons t-tests for both the overall comfort ratings and ratings based on the width of the curb lane, 5 out of 13 tests in both cases indicated significance (at $\alpha = 0.05$), suggesting some differences in the video vs. field ratings for five sites. The curb lane widths, speeds, and traffic volumes for all 13 sites are shown in table 35. The sites with significant t-statistics (sites 6, 7, 8, 10, and 13) do not appear, as a group, to result in any

Table 35. Geometric and operational characteristics of the pilot study sites.

Site	Street	Number of Lanes	Curb Lane Width (m)	Posted Speed Limit (km/h)	85th %tile Speed (km/h)	AADT
1	Regent	4	3.4	40	53	18650
2	Bluff	2	3.7	40	48	3550
3	University	4	3.8	56	68	16700
4	Gammon	2	5.5	56	56	15900
5	Glenway18	2	5.5	40	48	5400
6	Glenway10	2	3.1	40	48	5400
7	Odana	4	3.4	56	60	18800
8	McKenna	4	4.3	56	64	15400
9	Beltline	2	4.4	48	53	5450
10	Milwaukee	4	4.3	56	53	20250
11	Atwood	4	3.4	40	61	18250
12	Sherman	4	3.4	48	55	17850
13	Northport	4	3.8	56	72	26650

consistent pattern with respect to any of the variables, which is greatly different from the remaining eight sites that produced consistent ratings. However, further examination of the field observation data revealed that a large number of participants viewed site number 8 in the field when there was an unusually low traffic volume. This fact may have resulted in the significantly lower field rating for this site. The other four sites had significantly higher field ratings. At three of these four locations (sites 7, 10, and 13), more than half of the participants observed either a truck or bus during the field rating period, which may have produced a higher rating than the video clip of those sites since no trucks or buses were included in the primary video clips; at only one of the eight nonsignificant sites did that many participants observe a truck or bus. Finally, the fourth location with a significantly higher field rating was the site with the narrowest lane width (3.1 m), which may have simply been more intimidating in the field compared with video than the larger lane widths.

Appendix

C

Survey instruments

This appendix contains the forms, instructions, and rating scales used in the data collection efforts in both the pilot study and the primary research effort. Figure 22 is an example of a completed questionnaire (with the name omitted); this questionnaire was completed by all study participants and used to assess their experience levels as bicyclists. Figure 23 shows the instructions used during the pilot study for both the field survey and video survey; the accompanying rating scale is shown in figure 24. Examples of completed data collection forms from the pilot effort are provided in figure 25.

Figure 26 is an example of a completed video editing form that was used to record volumes for 10-s intervals over the 15-min taping period; it was from this form that the video clips were selected. The instructions used for the video survey of midblock segments in the primary data collection effort are provided in figure 27. The instructions used for the intersection survey are shown in figure 28; one set is for the individuals who were asked to rate five variables while the other set is for those who rated only one variable. The rating scale used for both surveys is shown in figure 29. Examples of completed data collection forms from each type of survey are provided in figures 30 and 31.

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BICYCLIST EXPERIENCE QUESTIONNAIRE

Name ______________________ Date 7/21/96

Sex ✓ M __ F Age 40

1. Do you ride in the city? Yes ✓ No ___

   If yes, what is the purpose of your bicycle trips? (Select as many categories as applicable; the total should add to 100 percent.)

   a. Recreation/exercise 75 %
   b. Commuting to/from work or school ___%
   c. Shopping ___%
   d. Visiting 25%
   e. Other __________ ___%

2. On which of the following do you typically ride? (Select as many categories as applicable; the total should add to 100 percent.)

   a. Major streets 15 %
   b. Residential streets 45 %
   c. Bicycle paths/trails 30 %
   d. Sidewalks 10 %
   e. Other ___%

3. How many trips do you make on your bicycle during a typical week? (A trip is defined as going from an origin to a destination; e.g., traveling to work from home is one trip and traveling from work to home is a second trip.)

   a. < 5 b. 5 - 10 c. > 10

4. How many days per week do you typically ride your bicycle? 4

5. How many miles per week do you typically ride on urban or suburban streets?

   a. < 5 mi b. 5 - 20 mi c. 20 - 40 mi d. > 40 mi

6. Do you ever choose not to ride your bicycle due to adverse weather conditions?

   Yes ✓ No ____

   If yes, under which conditions will you not ride (check all that apply)?

   Threat of rain ____ Drizzle ____ Steady rain ✓
   Heavy rain ✓ Snow/Ice ✓ Fog ____
   Cold weather ____ (below what temperature 20 F)
   Hot weather ____ (above what temperature ____ F)

7. How would you classify yourself with respect to the experience you have riding on urban and suburban streets? (Check one)

   ___ I feel comfortable riding under most traffic conditions, including major streets with busy traffic and higher speeds.

   ✓ I only feel comfortable riding on streets with less traffic and lower speeds, on streets with bicycle lanes, or on sidewalks.

Figure 22. A completed questionnaire.

BICYCLE COMPATIBILITY INDEX STUDY
VIDEO SURVEY INSTRUCTIONS - MADISON, WI

In a moment, you are going to watch a videotape which contains 60 clips showing different roadway conditions. As you watch each clip, I want you to pay particular attention to three specific aspects (*illustrate with a videotape*):

- the amount of traffic going in the direction away from you,
- the speed of this traffic, and
- the width or space available to you to ride your bicycle in this same direction.

As you look at each video clip, I want you to indicate how compatible or good you think the road is for bicycling. In other words, I want you to rate each roadway with respect to how comfortable you would be riding there, where comfort is defined by the level of risk you would feel as a bicyclist. The scale you are going to use in rating these segments is in front of you. It is numerically ordered in terms of the level of perceived risk. If you see the roadway condition as presenting virtually no risk to you as a bicyclist, you would rate the condition as a "1." If you see the roadway condition as presenting a risk that is so high that you would never ride under that condition, you would rate the condition as a "6." If you see the roadway condition as something between these two extremes, use the values from 2 to 5 to indicate your level of perceived risk.

As you can see on the rating sheet, there are four columns; one for volume (or amount of traffic), one for speed, one for lane width, and one for overall As you view each video clip, I want you to provide a perceived risk rating of 1 to 6, as we just discussed, for each of the three conditions shown in that particular clip (volume, speed, and width of the lane in which you would be riding), each one independently of the other two conditions. For example, as you are watching the clip, I want you to provide a rating of 1 to 6 with respect to the amount of risk you feel the traffic volume on that roadway presents to you as a bicyclist. Then you will provide a rating of 1 to 6 based on the amount of risk you feel from the speed of the traffic. Next you will provide a rating of 1 to 6 based on the amount of risk you feel from the width of the curb lane or space available to ride your bicycle in the road. Finally, you will provide a rating of 1 to 6 for the roadway as a whole which should represent your perceived risk based on the three measures just noted plus any other measures that you may consider important in determining your level of risk as a bicyclist. You may rate the volume, speed, and lane width in any order. The overall rating should be done last.

Each video clip is approximately 40 seconds in length. When there are 10 seconds remaining, a beep will be heard. During these last 10 seconds, you should complete the ratings for that roadway. Between consecutive video clips, there will be approximately 5 seconds in which the screen is blank. During each blank screen, I will indicate which numbered video clip is about to be shown.

Before we begin, are there any questions?

BICYCLE COMPATIBILITY INDEX STUDY
FIELD SURVEY INSTRUCTIONS - MADISON, WI

This morning, we are going to several specific sites on roadways here in Madison. When we get to a site, I will park the van and we will proceed to a location along the roadside. When we reach that location, I want you to pay particular attention to three specific aspects (*illustrate with a videotape*):

- the amount of traffic going in the direction away from you;
- the speed of this traffic, and
- the width or space available to you to ride your bicycle in this same direction.

As you examine the roadway, I want you to indicate how compatible or good you think the road is for bicycling. In other words, I want you to rate each roadway with respect to how comfortable you would be riding there, where comfort is defined by the level of risk you would feel as a bicyclist. The scale you are going to use in rating these segments is in front of you. It is numerically ordered in terms of the level of perceived risk. If you see the roadway condition as presenting virtually no risk to you as a bicyclist, you would rate the condition as a "1." If you see the roadway condition as presenting a risk that is so high that you would never ride under that condition, you would rate the condition as a"6." If you see the roadway condition as something between these two extremes, use the values from 2 to 5 to indicate your level of perceived risk.

As you can see on the rating sheet, there are four columns; one for volume (or amount of traffic), one for speed, one for lane width, and one for overall. As you examine each roadway, I want you to provide a perceived risk rating of 1 to 6, as we just discussed, for each of the three conditions presently existing on the roadway (volume, speed, and width), each one independently of the other two conditions. For example, as you examining the roadway, I want you to provide a rating of 1 to 6 with respect to the amount of risk you feel the traffic volume on that roadway presents to you as a bicyclist. Then you will provide a rating of 1 to 6 based on the amount of risk you feel from the speed of the traffic. Next you will provide a rating of 1 to 6 based on the amount of risk you feel from the width of the curb lane or space available to ride your bicycle in the road. Finally, you will provide a rating of 1 to 6 for the roadway as a whole which should represent your perceived risk based on the three measures just noted plus any other measures that you may consider important in determining your level of risk as a bicyclist. You may rate the volume, speed, and lane width in any order. The overall rating should be done last.

We will spend no more than 2 minutes at each roadway location. We will then return to the van and proceed to the next location.

Before we go to the van, are there any questions?

Figure 23. Pilot survey instructions.

BICYCLE COMPATIBILITY INDEX STUDY

VIDEO/FIELD SURVEY RATING SCALE — MADISON, WI

PERCEIVED RISK

1 — VIRTUALLY NO RISK

2

3

4

5

6 — UNACCEPTABLY HIGH RISK

Figure 24. Rating scale used in the pilot study.

BICYCLE COMPATIBILITY INDEX STUDY
VIDEO SURVEY FORM - MADISON, WI

SUBJECT NO. 17 DATE: 6/20/95 PAGE 1

Segment No.	Ratings			
	Volume	Speed	Width	Overall
1	1	2	2	2
2	3	3	5	5
3	2	2	4	4
4	3	4	4	4
5	2	3	4	3
6	1	1	1	1
7	2	3	1	2
8	3	3	3	3
9	3	1	1	2
10	4	3	5	5
11	4	4	1	2
12	4	2	4	4
13	2	2	6	5
14	3	3	2	2
15	4	3	4	4
16	3	4	4	4
17	4	3	5	5
18	3	3	5	4
19	4	4	3	4
20	5	3	6	5
21	1	2	2	2
22	2	1	2	2
23	3	3	6	5
24	3	3	2	2
25	2	2	5	4
26	4	4	5	5
27	3	3	6	5
28	4	4	4	4
29	2	1	1	1
30	1	4	3	3

BICYCLE COMPATIBILITY INDEX STUDY
FIELD SURVEY FORM - MADISON, WI

SUBJECT NO. 17 DATE: 6/21/95

Segment No.	Ratings			
	Volume	Speed	Width	Overall
1	2	3	4	3
2	2	1	3	2
3	2	3	3	3
4	4	3	1	2
5	1	1	1	1
6	2	2	5	4
7	3	3	5	5
8	1	2	1	1
9	1	1	1	1
10	3	3	3	3
11	4	3	6	5
12	2	2	6	5
13	3	3	4	3

Figure 25. Examples of completed field survey forms.

BICYCLE COMPATIBILITY INDEX STUDY

VIDEO EDITING FORM

SITE NO. 3312 CITY Corvallis TAPE NO. 3 TAPE POSITION 0:00:00

Time Interval	LVol/ TVol*	Time Interval	LVol/ TVol	Time Interval	LVol/ TVol	Time Interval	LVol/ TVol
0:00 - 0:10	4	4:00 - 4:10	0	8:00 - 8:10	1	12:00 - 12:10	0
0:10 - 0:20	4	4:10 - 4:20	0	8:10 - 8:20	2	12:10 - 12:20	1
0:20 - 0:30	0	4:20 - 4:30	1	8:20 - 8:30	3	12:20 - 12:30	3
0:30 - 0:40	3	4:30 - 4:40	4 °	8:30 - 8:40	2	12:30 - 12:40	1
0:40 - 0:50	0	4:40 - 4:50	5	8:40 - 8:50	2	12:40 - 12:50	1
0:50 - 1:00	0	4:50 - 5:00	2	8:50 - 9:00	1	12:50 - 13:00	1
1:00 - 1:10	0	5:00 - 5:10	2	9:00 - 9:10	0	13:00 - 13:10	0
1:10 - 1:20	0	5:10 - 5:20	0	9:10 - 9:20	0	13:10 - 13:20	4
1:20 - 1:30	1	5:20 - 5:30	1	9:20 - 9:30	4	13:20 - 13:30	2
1:30 - 1:40	4	5:30 - 5:40	2	9:30 - 9:40	4	13:30 - 13:40	0
1:40 - 1:50	4	5:40 - 5:50	5	9:40 - 9:50	1	13:40 - 13:50	0
1:50 - 2:00	3	5:50 - 6:00	5 C	9:50 - 10:00	2	13:50 - 14:00	0
2:00 - 2:10	0	6:00 - 6:10	2	10:00 - 10:10	0	14:00 - 14:10	0
2:10 - 2:20	0	6:10 - 6:20	1	10:10 - 10:20	1	14:10 - 14:20	0
2:20 - 2:30	0	6:20 - 6:30	0	10:20 - 10:30	1	14:20 - 14:30	3
2:30 - 2:40	0	6:30 - 6:40	1	10:30 - 10:40	1	14:30 - 14:40	4
2:40 - 2:50	0	6:40 - 6:50	2	10:40 - 10:50	0	14:40 - 14:50	3
2:50 - 3:00	2	6:50 - 7:00	4 *	10:50 - 11:00	2	14:50 - 15:00	1
3:00 - 3:10	3	7:00 - 7:10	4 **	11:00 - 11:10	* Curb lane volume/total volume		
3:10 - 3:20	4	7:10 - 7:20	1 NG	11:10 - 11:20	B - bus in clip, T - truck in clip		
3:20 - 3:30	4	7:20 - 7:30	0	11:20 - 11:30	C - bicyclist in clip		
3:30 - 3:40	0	7:30 - 7:40	1	11:30 - 11:40	RT - right turning vehicle in clip		
3:40 - 3:50	0	7:40 - 7:50	4	11:40 - 11:50	PK - parking vehicle in clip		
3:50 - 4:00	0	7:50 - 8:00	5	11:50 - 12:00	NG - clip cannot be used		

* Curb Lane Volume/Total Volume (for multilane sites only)

Figure 26. Completed video editing form.

BICYCLE COMPATIBILITY INDEX STUDY
VIDEO SURVEY INSTRUCTIONS

In a moment, you are going to watch a videotape which contains 80 clips showing different roadway segments. As you watch each clip, I want you to pay particular attention to three specific aspects:

- the amount of traffic going in the direction away from you,
- the speed of this traffic, and
- the width or space available to you to ride your bicycle in this same direction

As you look at each video clip, I want you to indicate how compatible or good you think the road is for bicycling. In other words, I want you to rate each roadway with respect to how comfortable you would be riding there, where comfort is defined by how likely you are to ride on a given roadway under the speed, volume, and lane widths shown. Comfort does not refer to the smoothness of the ride or the quality of the paved surface. The scale you are going to use in rating these segments is numerically ordered in terms of the level of comfort. If you see the roadway and traffic conditions being such that you would not hesitate to ride there and thus, you consider it to be extremely comfortable, you would rate the roadway as a "1." If you see the conditions being such that you would never ride there and thus you consider it to be extremely uncomfortable, you would rate the roadway as a "6." If you see the roadway and traffic conditions as something between these two extremes, use the values from 2 to 5 to indicate your level of comfort.

As you can see on the rating sheet, there are four columns; one for volume (or amount of traffic), one for speed, one for lane width, and one for overall. As you view each video clip, I want you to provide a comfort level rating of 1 to 6, as we just discussed, for each of the three conditions shown in that particular clip (volume, speed, and width of the lane in which you would be riding). For example, as you are watching the clip, I want you to provide a rating of 1 to 6 with respect to how comfortable you would feel as a bicyclist considering the number of vehicles on that roadway. Then you will provide a rating of 1 to 6 based on how comfortable you would feel considering the speed of the traffic. Next you will provide a rating of 1 to 6 based on how comfortable you would feel considering the space available to you to ride your bicycle in the road. Finally, you will provide a rating of 1 to 6 for the roadway as a whole which should represent your overall comfort level based on the three measures just noted plus any other measures that you may consider important in determining your comfort level as a bicyclist. You may rate the volume, speed, and lane width in any order. The overall rating should be done last.

Each video clip is approximately 40 seconds in length. When there are 10 seconds remaining, you will hear a beep. During these last 10 seconds, you should complete the ratings for that roadway. Between consecutive video clips, there will be approximately 5 seconds in which the screen is black, with the exception of a number in the upper left-hand corner identifying the upcoming clip.

Before we begin, are there any questions?

Figure 27. Video survey instructions for rating midblock segments.

BICYCLE COMPATIBILITY INDEX STUDY
INTERSECTION VIDEO SURVEY INSTRUCTIONS

Now you are going to watch a videotape which contains 19 clips showing different intersections. As you look at each video clip, I want you to indicate how compatible or good you think the intersection is for through bicyclists. In other words, I want you to rate each roadway with respect to how comfortable you would be riding straight through the intersection in the presence of the right-turning traffic, where comfort is defined by how likely you are to ride through that intersection under the roadway and traffic conditions shown. Again, comfort does not refer to the smoothness of the ride or the quality of the paved surface. You will use the same scale as before. If you see the roadway and traffic conditions as being such that you would not hesitate to ride through the intersection and thus, you consider it to be extremely comfortable, you would rate the intersection as a "1." If you see the conditions as being such that you would never ride through the intersection, and thus you consider it to be extremely uncomfortable, you would rate the intersection as a "6." If you see the roadway and traffic conditions as something between these two extremes, use the values from 2 to 5 to indicate your level of comfort.

Each video clip is approximately 40 seconds in length. When there are 10 seconds remaining, you will hear a beep. During these last 10 seconds, you should complete the ratings for that roadway. Between consecutive video clips, there will be approximately 5 seconds in which the screen is black, with the exception of a number in the upper left-hand corner identifying the upcoming clip.

Before we begin, are there any questions?

BICYCLE COMPATIBILITY INDEX STUDY
INTERSECTION VIDEO SURVEY INSTRUCTIONS

Now you are going to watch a videotape which contains 19 clips showing different intersections. As you watch each clip, I want you to pay particular attention to four specific aspects:

- the amount of right-turning traffic,
- the speed of this traffic on the approach to the intersection,
- the space available to you to ride your bicycle through this intersection, and
- the clarity of any signs and markings indicating appropriate paths for bicyclists and/or motorists

As you look at each video clip, I want you to indicate how compatible or good you think the intersection is for through bicyclists. In other words, I want you to rate each roadway with respect to how comfortable you would be riding straight through the intersection in the presence of the right-turning traffic, where comfort is defined by how likely you are to ride through that intersection under the speed, volume, and other conditions shown. Again, comfort does not refer to the smoothness of the ride or the quality of the paved surface. You will use the same scale as before. If you see the roadway and traffic conditions being such that you would not hesitate to ride through the intersection and thus, you consider it to be extremely comfortable, you would rate the intersection as a "1." If you see the conditions being such that you would never ride through the intersection, and thus you consider it to be extremely uncomfortable, you would rate the intersection as a "6." If you see the roadway and traffic conditions as something between these two extremes, use the values from 2 to 5 to indicate your level of comfort.

As you can see on the rating sheet, there are five columns; one for right-turning volume (or amount of traffic), one for approach speed, one for available space, one for signs and markings, and one for overall. As you view each video clip, I want you to provide a comfort level rating of 1 to 6, as we just discussed, for each of the conditions shown in that particular clip. For example, as you are watching the clip, I want you to provide a rating of 1 to 6 with respect to how comfortable you are with the signs and markings indicating appropriate paths for bicyclists and motorists. Then you will provide a rating of 1 to 6 with respect to how comfortable you would feel as a bicyclist considering the number of right-turning vehicles at that intersection. Next you will provide a rating of 1 to 6 based on how comfortable you would feel considering the speed of the traffic approaching the intersection. Then you will provide a rating of 1 to 6 based on how comfortable you would feel considering the space available to you to ride your bicycle through the intersection. Finally, you will provide a rating of 1 to 6 for the roadway as a whole which should represent your overall comfort level based on the four measures just noted plus any other measures that you may consider important in determining your comfort level as a bicyclist. You may rate the volume, speed, available space and signs/markings in any order. The overall rating should be done last.

Each video clip is approximately 40 seconds in length. When there are 10 seconds remaining, you will hear a beep. During these last 10 seconds, you should complete the ratings for that roadway. Between consecutive video clips, there will be approximately 5 seconds in which the screen is black, with the exception of a number in the upper left-hand corner identifying the upcoming clip.

Before we begin, are there any questions?

Figure 28. Video survey instructions for rating intersections.

BICYCLE COMPATIBILITY INDEX STUDY

VIDEO/FIELD SURVEY RATING SCALE

COMFORT LEVEL

1 — EXTREMELY COMFORTABLE

2

3

4

5

6 — EXTREMELY UNCOMFORTABLE

Figure 29. Rating scale used in the primary data collection effort.

BICYCLE COMPATIBILITY INDEX STUDY
VIDEO SURVEY FORM

NAME ______________________ DATE: 7/24/96 PAGE 1

Segment No.	Ratings			
	Volume	Speed	Width	Overall
1	3	4	2	3
2	2	2	5	5
3	2	5	6	6
4	3	2	6	4
5	3	3	3	3
6	3	2	4	3
7	1	3	2	1
8	1	1	1	1
9	1	1	2	1
10	1	2	1	1
11	2	1	1	3
12	1	3	2	1
13	1	1	1	1
14	6	2	6	6
15	1	1	1	1
16	1	3	2	1
17	3	2	1	1
18	2	4	5	5
19	6	6	6	6
20	1	1	1	1
21	6	6	6	6
22	1	1	2	1
23	2	3	1	1
24	1	1	2	1
25	2	2	6	2
26	6	6	6	6
27	1	1	2	2
28	3	2	3	1

Figure 30. Example of a completed video survey form for midblock segments.

BICYCLE COMPATIBILITY INDEX STUDY
VIDEO SURVEY FORM - INTERSECTION

NAME ____________ DATE 7-23-96

Segment No.	Ratings				
	Signs/ Markings	Available Space	Approach Speed	Right-Turn Volume	Overall
1	1	2	5	4	3
2	5	5	4	2	4
3	3	4	4	4	3
4	1	2	3	2	2
5	5	2	4	1	2
6	3	5	[illegible]	3	5
7	1	3	4	2	3
8	2	3	2	2	2
9	2	4	1	3	2
10	1	1	2	2	2
11	4	3	5	5	5
12	3	5	5	3	4
13	1	1	1	2	1
14	2	2	3	2	2
15	2	3	4	2	2
16	4	3	3	3	3
17	3	3	2	2	3
18	5	3	3	3	3
19	2	3	4	1	2

BICYCLE COMPATIBILITY INDEX STUDY
VIDEO SURVEY FORM - INTERSECTION

NAME ____________ DATE 7-23-96

Segment No.	Rating
1	5
2	6
3	6
4	5
5	4
6	5
7	5
8	2
9	6
10	2
11	3
12	6
13	2
14	4
15	1
16	2
17	4
18	2
19	2

Figure 31. Example of completed video survey forms for intersections.

Appendix

D

English Units BCI Model

While many States and municipalities have converted to the metric system of measurement, other localities still employ the English system or the geometric and operational information contained in the data bases is in English units. For these reasons, an English units version of the BCI model is provided in table 36.

Table 36. English units version of the Bicycle Compatibility Index (BCI) model.

$$\mathbf{BCI} = 3.67 - 0.966\mathbf{BL} - 0.125\mathbf{BLW} - 0.152\mathbf{CLW} + 0.002\mathbf{CLV} + 0.0004\mathbf{OLV} + 0.035\mathbf{SPD} + 0.506\mathbf{PKG} - 0.264\mathbf{AREA} + \mathbf{AF}$$

where:

BL = presence of a bicycle lane or paved shoulder ≥ 3.0 ft
no = 0
yes = 1

BLW = bicycle lane (or paved shoulder) width
ft (to the nearest tenth)

CLW = curb lane width
ft (to the nearest tenth)

CLV = curb lane volume
vph in one direction

OLV = other lane(s) volume - same direction
vph

SPD = 85th percentile speed of traffic
mi/h

PKG = presence of a parking lane with more than 30 percent occupancy
no = 0
yes = 1

AREA = type of roadside development
residential = 1
other type = 0

AF = $f_t + f_p + f_{rt}$

where:

f_t = adjustment factor for truck volumes (*see below*)

f_p = adjustment factor for parking turnover (*see below*)

f_{rt} = adjustment factor for right-turn volumes (*see below*)

Adjustment Factors

Hourly Curb Lane Large Truck Volume[1]	f_t
≥ 120	0.5
60 - 119	0.4
30-59	0.3
20-29	0.2
10-19	0.1
< 10	0.0

Parking Time Limit (min)	f_p
≤ 15	0.6
16 - 30	0.5
31 - 60	0.4
61 - 120	0.3
121 - 240	0.2
241- 480	0.1
> 480	0.0

Hourly Right-Turn Volume[2]	f_{rt}
≥ 270	0.1
< 270	0.0

[1] Large trucks are defined as all vehicles with six or more tires.
[2] Includes total number of right turns into driveways or minor intersections along a roadway segment.

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